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Guidelines for the Use of Stream Reconnaissance Record Sheets in the Field

by *Colin R. Thorne*
University of Nottingham

Approved For Public Release; Distribution Is Unlimited

Prepared for Headquarters, U.S. Army Corps of Engineers

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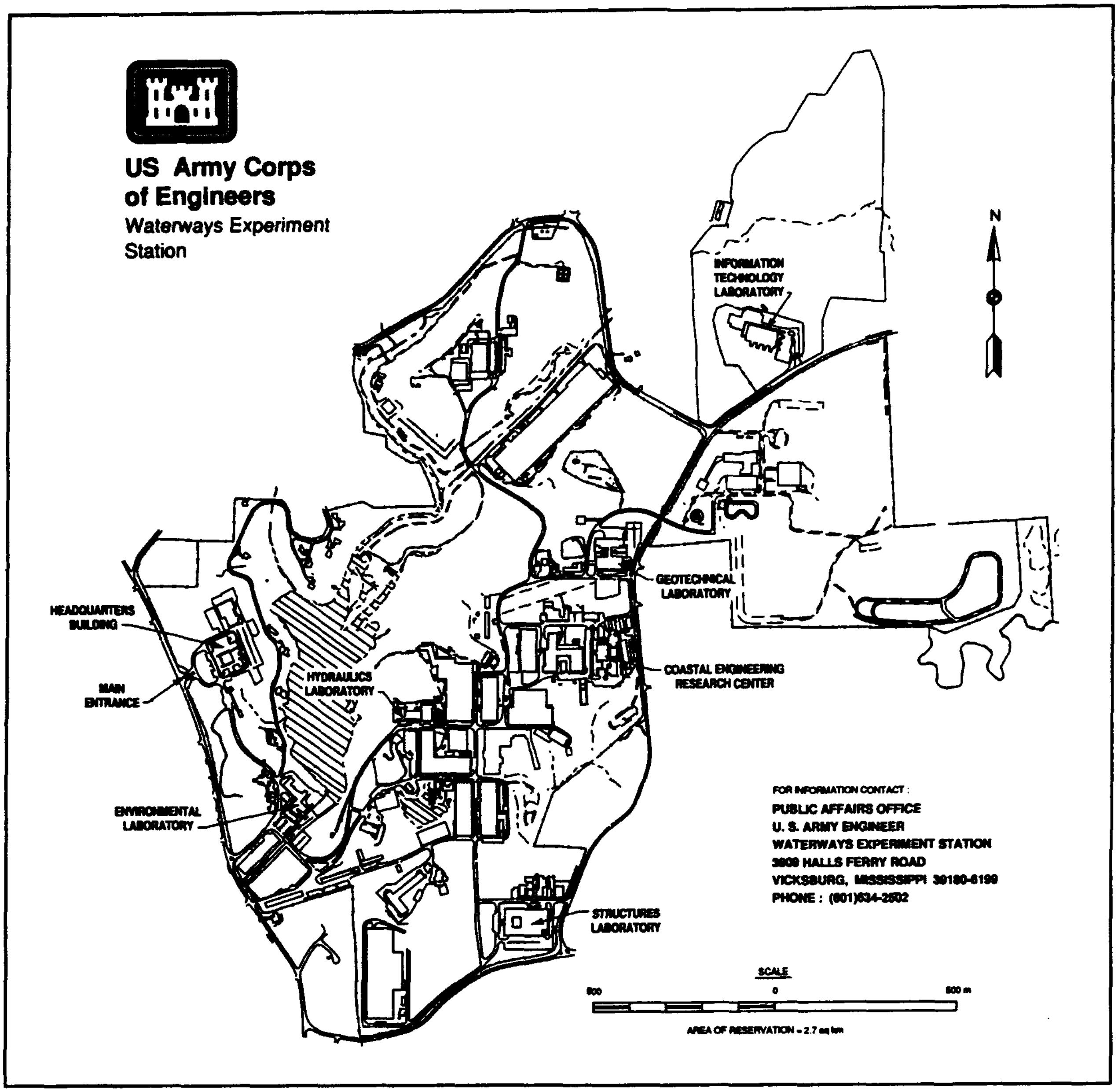

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Preface

This report was prepared by Dr. Colin R. Thorne, University of Nottingham, United Kingdom, for the U.S. Army Engineer Waterways Experiment Station (WES) Hydraulics Laboratory (HL), Vicksburg, MS. The study was sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE), under the Flood Control Channels Research Program (FCCRP). The WES FCCRP Program Manager was Mr. William A. Thomas, Waterways Division (WD), HL. Technical Monitor, HQUSACE, was Mr. Thomas E. Munsey. The study was done under Work Unit No. 32550, "River Bend System Hydraulics-Resisting Force Component" and was conducted during the period from July 1990 to February 1992.

Mr. Michael J. Trawle, Chief, Mathematical Modeling Branch, WD, monitored the study under the supervision of Messrs. Marden B. Boyd, Chief, WD; Frank A. Herrmann, Director, HL; and Richard A. Sager, Assistant Director, HL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

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CONTENTS

STREAM RECONNAISSANCE RECORD SHEET

Developed by Colin R. Thorne
for the US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

SECTION 1 - SCOPE AND PURPOSE

Brief Problem Statement:-

Purpose of Stream Reconnaissance:-

Logistics of Reconnaissance Trip:-

RIVER LOCATION DATE

PROJECT STUDY REACH From To

SHEET COMPLETED BY

RIVER STAGE TIME: START TIME: FINISH

General Notes and Comments on Reconnaissance Trip:-

SECTION 2 - REGION AND VALLEY DESCRIPTION

PART 1: AREA AROUND RIVER VALLEY

Terrain: Mountains [ ] Uplands [ ] Hills [ ] Plains [ ] Lowlands [ ]

Drainage Pattern: Dendritic [ ] Parallel [ ] Trellis [ ] Rectangular [ ] Radial [ ] Annular [ ] Multi-Basin [ ] Contorted [ ]

Surface Geology: Bed rock [ ] Weathered Soils [ ] Glacial Moraine [ ] Glacio/Fluvial [ ] Fluvial [ ] Lake Deposits [ ] Wind blown (loess) [ ]

Rock Type: Sedimentary [ ] Metamorphic [ ] Igneous [ ] None [ ]

Specific Rock Types (if known)

Land Use: Natural [ ] Managed [ ] Cultivated [ ] Urban [ ] Suburban [ ]

Vegetation: Tropical forest [ ] Temperate forest [ ] Boreal forest [ ] Woodland [ ] Savanna [ ] Temperate grassland [ ] Desert scrub [ ] Extreme Desert [ ] Tundra or Alpine [ ] Agricultural land [ ]

Notes and Comments:-

PART 2: RIVER VALLEY AND VALLEY SIDES

Location of River: In Valley [ ] On Alluvial Fan [ ] On Alluvial Plain [ ] In a Delta [ ] In Old Lake Bed [ ]

Valley Shape: Symmetrical [ ] Asymmetrical [ ]

Height: < 20 feet [ ] 20-50 feet [ ] 50-100 feet [ ] 100-200 feet [ ] 200-500 feet [ ] >500 feet [ ]

Side Slope Angle: < 5degrees [ ] 5-10 degrees [ ] 10-20 degrees [ ] 20-50 degrees [ ] >50 degrees [ ]

Valley Side Failures: None [ ] Occasional [ ] Frequent [ ]

Failure Locations: None [ ] Away from river [ ] Along river (Undercut) [ ]

Interpretative Observations

Material Type: *Bedrock* [ ] *Soils* [ ] *Unconsolidated debris* [ ]

Failure Type *(see Sketches in Manual)*

Severity of Problems: *Insignificant* [ ] *Mild* [ ] *Significant* [ ] *Serious* [ ] *Catastrophic* [ ]

Level of Confidence in answers (Circle one)

0 10 20 30 40 50 60 70 80 90 100 %

Notes and Comments:-

PART 3: FLOOD PLAIN (VALLEY FLOOR)

Valley Floor Type: None [ ] Indefinite [ ] Fragmentary [ ] Continuous [ ]

Valley Floor Data: None [ ] < 1 river width [ ] 1 - 5 river widths [ ] 5-10 river widths [ ] >10 river widths [ ]

Flow Resistance*

Left Overbank Manning n value ___

Right Overbank Manning n value ___ (* note: n value for channel is recorded in Part 6)

Surface Geology: Bed rock [ ] Glacial Moraine [ ] Glacio/Fluvial [ ] Fluvial: Alluvium [ ] Fluvial: Backswamp [ ] Lake Deposits [ ] Wind Blown (Loess) [ ]

Land Use: Natural [ ] Managed [ ] Cultivated [ ] Urban [ ] Suburban [ ] Industrial [ ]

Vegetation: None [ ] Unimproved Grass [ ] Improved Pasture [ ] Orchards [ ] Arable Crops [ ] Shrubs [ ] Deciduous Forest [ ] Coniferous Forest [ ] Mixed Forest [ ]

Riparian Buffer Strip: None [ ] Indefinite [ ] Fragmentary [ ] Continuous [ ]

Strip Width: None [ ] < 1 river width [ ] 1 - 5 river widths [ ] > 5 river widths [ ]

Notes and Comments:-

PART 4: VERTICAL RELATION OF CHANNEL TO VALLEY

Terraces: None [ ] Indefinate [ ] Fragmentary [ ] Continuous [ ]

Number of Terraces ___

Trash Lines: Absent [ ] Present [ ]

Ht above flood plain (ft) ___

Overbank Deposits: None [ ] Silt [ ] Fine sand [ ] Medium sand [ ] Coarse sand [ ] Gravel [ ] Boulders [ ]

Levees: None [ ] Natural [ ] Man-made [ ]

Levee Description: None [ ] Indefinite [ ] Fragmentary [ ] Continuous [ ] Left Bank [ ] Right Bank [ ] Both Banks [ ]

Levee Data: Height (f) [ ] Side Slope (o) [ ]

Levee Condition: None [ ] Intact [ ] Local Failures [ ] Frequent failures [ ]

Interpretative Observations

Present Status: *Adjusted* [ ] *Incised* [ ] *Aggraded* [ ]

Instability Status: *Stable* [ ] *Degrading* [ ] *Aggrading* [ ]

Problem Severity: *Insignificant* [ ] *Moderate* [ ] *Serious* [ ]

Problem Extent: *None* [ ] *Local* [ ] *General* [ ] *Reach scale* [ ] *System wide* [ ] *Regional* [ ]

Level of Confidence in answers (Circle one)

0 10 20 30 40 50 60 70 80 90 100 %

Notes and Comments:-

PART 5: LATERAL RELATION OF CHANNEL TO VALLEY

Planform: Straight [ ] Sinuous [ ] Irregular [ ] Regular meanders [ ] Irregular meanders [ ] Tortuous meanders [ ] Braided [ ]

Planform Data: Bend Radius ___ Meander belt width ___ Wavelength ___ Meander Sinuosity ___

Location in Valley: Left [ ] Middle [ ] Right [ ]

Lateral Activity: None [ ] Meander progression [ ] Increasing amplitude [ ] Progression+cut-offs [ ] Irregular erosion [ ] Avulsion [ ] Braiding [ ]

Floodplain Features: None [ ] Meander scars [ ] Scroll bars+sloughs [ ] Oxbow lakes [ ] Irregular terrain [ ] Abandoned channel [ ] Braided Deposits [ ]

Interpretative Observations

Present Status: *Adjusted* [ ] *Over wide* [ ] *Too narrow* [ ]

Instability Status: *Stable* [ ] *Widening* [ ] *Narrowing* [ ]

Problem Severity: *Insignificant* [ ] *Moderate* [ ] *Serious* [ ]

Problem Extent: *None* [ ] *Local* [ ] *General* [ ] *Reach scale* [ ] *System wide* [ ] *Regional* [ ]

Level of Confidence in percent (Circle one)

0 10 20 30 40 50 60 70 80 90 100 %

Notes and Comments:-

SECTION 3 - CHANNEL DESCRIPTION

PART 6: CHANNEL DESCRIPTION

Dimensions

Ave. top bank width ___
Ave. channel depth ___
Ave. water width ___
Ave. water depth ___
Reach slope ___
Mean velocity ___
Manning's n value ___

Flow Type

None ☐
Uniform/Tranquil ☐
Uniform/Rapid ☐
Pool+Riffle ☐
Steep + Tumbling ☐
Steep + Step/pool ☐
(Note: Flow type on day of observation)

Bed Controls

None ☐
Occasional ☐
Frequent ☐
Confined ☐
Number of controls ___

Control Types

None ☐
Solid Bedrock ☐
Weathered Bedrock ☐
Boulders ☐
Gravel armor ☐
Cohesive Materials ☐
Bridge protection ☐
Grade control structures ☐

Width Controls

None ☐
Occasional ☐
Frequent ☐
Confined ☐
Number of controls ___

Control Types

None ☐
Bedrock ☐
Boulders ☐
Gravel armor ☐
Revetments ☐
Cohesive Materials ☐
Bridge abutments ☐
dykes or groynes ☐

Notes and Comments:-

PART 7: BED SEDIMENT DESCRIPTION

Bed Material

Clay ☐
Silt ☐
Sand ☐
Sand and gravel ☐
gravel and cobbles ☐
cobbles + boulders ☐
boulders + bedrock ☐
Bed rock ☐

Bed Armour

None ☐
Static-armour ☐
Mobile-armour ☐

Sediment Depth

Depth of loose
Sediment in bed (ft) ___

Surface Size Data

D50 (mm) ___
D84 (mm) ___
D16 (mm) ___

Substrate Size Data

D50 (mm) ___
D84 (mm) ___
D16 (mm) ___

Bed Forms (Sand)

Flat bed (None) ☐
Ripples ☐
Dunes ☐
Bed form height (ft) ___

Island or Bars

None ☐
Occasional ☐
Frequent ☐

Bar Types

None ☐
Pools and riffles ☐
Alternate bars ☐
Point bars ☐
Mid-channel bars ☐
Diagonal bars ☐
Junction bars ☐
Sand waves + dunes ☐

Bar Surface data

D50 (mm) ___
D84 (mm) ___
D16 (mm) ___

Bar Substrate data

D50 (mm) ___
D84 (mm) ___
D16 (mm) ___

Notes and Comments:-

Channel Sketch Map

Map Symbols

Study reach limits		North point		Cut bank		Photo point	
Cross-section	A———A'	flow direction		exposed island/bar		Sediment sampling point	
Bank profile		impinging flow		structure		Significant vegetation	

Representative Cross-section

SECTION 4 - LEFT BANK SURVEY

PART 8: LEFT BANK CHARACTERISTICS

Type
- Noncohesive ☐
- Cohesive ☐
- Composite ☐
- Layered ☐
- Even Layers ☐
- Thick+thin layers ☐
- Number of layers ___

Protection Status
- Unprotected ☐
- Hard points ☐
- Toe protection ☐
- Revetments ☐
- Dyke Fields ☐

Bank Materials
- Silt/clay ☐
- Sand/silt/clay ☐
- Sand/silt ☐
- Sand ☐
- Sand/gravel ☐
- Gravel ☐
- Gravel/cobbles ☐
- Cobbles ☐
- Cobbles/boulders ☐
- Boulders/bedrock ☐

Layer Thickness
- Material 1 (ft) ___
- Material 2 (ft) ___
- Material 3 (ft) ___
- Material 4 (ft) ___

Ave. Bank Height
- Average height (ft) ___

Ave. Bank Slope
- Average angle (o) ___

Bank Profile Shape
(see sketches in manual)

Tension Cracks
- None ☐
- Occasional ☐
- Frequent ☐

Crack Depth
Proportion of bank height ___

Distribution and Description of Bank Materials in Bank Profile

Material Type 1		Material Type 2		Material Type 3		Material Type 4	
Toe	☐	Toe	☐	Toe	☐	Toe	☐
Mid-Bank	☐	Mid-Bank	☐	Mid-Bank	☐	Mid-Bank	☐
Upper Bank	☐	Upper Bank	☐	Upper Bank	☐	Upper Bank	☐
Whole Bank	☐	Whole Bank	☐	Whole Bank	☐	Whole Bank	☐
D50 (mm)	___	D50 (mm)	___	D50 (mm)	___	D50 (mm)	___
sorting coefficient	___	sorting coefficient	___	sorting coefficient	___	sorting coef.	___

Notes and Comments:-

PART 9: LEFT BANK-FACE VEGETATION

Vegetation
- None/fallow ☐
- Artificially cleared ☐
- Grass and flora ☐
- Reeds and sedges ☐
- Shrubs ☐
- Saplings ☐
- Trees ☐

Tree Types
- None ☐
- Deciduous ☐
- Coniferous ☐
- Mixed ☐

Tree species (if known) ___

Orientation ___

Angle of leaning (o) ___

Density + Spacing
- None ☐
- Sparse/clumps ☐
- dense/clumps ☐
- Sparce/continuous ☐
- Dense/continuous ☐

Roots
- Normal ☐
- Exposed ☐
- Adventitious ☐

Location
- Whole bank ☐
- Upper bank ☐
- Mid-bank ☐
- Lower bank ☐

Diversity
- Mono-stand ☐
- Mixed stand ☐
- Climax-vegetation ☐

Health
- Healthy ☐
- Fair ☐
- Poor ☐
- Dead ☐

Age
- Imature ☐
- Mature ☐
- Old ☐

Height
- Short ☐
- Medium ☐
- Tall ☐
- Height (ft) ___

Lateral Extent
- Wide belt ☐
- Narrow belt ☐
- Single row ☐

Notes and Comments:-

Bank Profile Sketches

Profile Symbols

- Bank Top Edge
- Bank Toe
- Water's Edge
- Failed debris
- Attached bar
- Undercutting
- Engineered Structure
- Significant vegetation
- Vegetation Limit

PART 10: LEFT BANK EROSION

Erosion Location
- General
- Outside Meander
- Inside Meander
- Opposite a bar
- Behind a bar
- Opposite a structure
- Adjacent to structure
- Dstream of structure
- Ustream of structure
- Other (write in)

Present Status
- Intact
- Eroding:dormant
- Eroding:active
- Advancing:dormant
- Advancing:active

Rate of Retreat ft/yr (if applicable and known)

Rate of Advance ft/yr (if applicable and known)

Interpretative Observations

Severity of Erosion
- *Insignificant*
- *Mild*
- *Significant*
- *Serious*
- *Catastrophic*

Extent of Erosion
- *None*
- *Local*
- *General*
- *Reach Scale*
- *System Wide*

Processes
- *Parallel flow*
- *Impinging flow*
- *Piping*
- *Freeze/thaw*
- *Sheet erosion*
- *Rilling + gullying*
- *Wind waves*
- *Vessel Forces*
- *Ice rafting*
- *Other (write in)*

Distribution of Each Process on Bank

Process 1	***Process 2***
Toe (undercut)	*Toe (undercut)*
Lower bank	*Lower bank*
Upper bank	*Upper bank*
Whole bank	*Whole bank*
Process 3	***Process 4***
Toe (undercut)	*Toe (undercut)*
Lower bank	*Lower bank*
Upper bank	*Upper bank*
Whole bank	*Whole bank*

Level of Confidence in answers (Circle one)

0 10 20 30 40 50 60 70 80 90 100 %

Notes and Comments:-

PART 11: LEFT BANK GEOTECH FAILURES

Failure Location
- General
- Outside Meander
- Inside Meander
- Opposite a bar
- Behind a bar
- Opposite a structure
- Adjacent to structure
- Dstream of structure
- Ustream of structure
- Other (write in)

Present Status
- Stable
- Unreliable
- Unstable:dormant
- Unstable:active

Failure Scars+Blocks
- None
- Old
- Recent
- Fresh
- Contemporary

Interpretative Observations

Instability:Severity
- *Insignificant*
- *Mild*
- *Significant*
- *Serious*
- *Catastrophic*

Instability: Extent
- *None*
- *Local*
- *General*
- *Reach Scale*
- *System Wide*

Failure Mode
- *Soil/rock fall*
- *Shallow slide*
- *Rotational slip*
- *Slab-type block*
- *Cantilever failure*
- *Pop-out failure*
- *Piping failure*
- *Dry granular flow*
- *Wet earth flow*
- *Other (write in)*

Distribution of Each Mode on Bank

Mode 1	***Mode 2***
Toe	*Toe*
Lower bank	*Lower bank*
Upper bank	*Upper bank*
Whole bank	*Whole bank*
Mode 3	***Mode 4***
Toe	*Toe*
Lower bank	*Lower bank*
Upper bank	*Upper bank*
Whole bank	*Whole bank*

Level of Confidence in answers (Circle one)

0 10 20 30 40 50 60 70 80 90 100 %

Notes and Copmments:-

PART 12: LEFT BANK TOE SEDIMENT ACCUMULATION

Stored Bank Debris
- None
- Individual grains
- Aggregates+crumbs
- Root-bound clumps
- Small soil blocks
- Medium soil blocks
- Large soil blocks
- Cobbles/boulders
- Boulders

Vegetation
- None/fallow
- Artificially cleared
- Grass and flora
- Reeds and sedges
- Shrubs
- Saplings
- Trees

Age
- Immature
- Mature
- Old
- Age in Years

Tree species (if known)

Health
- Healthy
- Unhealthy
- Dead

Roots
- Normal
- Adventitious
- Exposed

Interpretative Observations

Toe Bank Profile
- *Planar*
- *Concave upward*
- *Convex upward*

Sediment Balance
- *Accumulating*
- *Steady State*
- *Undercutting*
- *Unknown*

Present Debris Storage
- *No bank debris*
- *Little bank debris*
- *Some bank debris*
- *Lots of bank debris*

Level of Confidence in answers (Circle one)

0 10 20 30 40 50 60 70 80 90 100 %

Notes and Comments:-

SECTION 5 - RIGHT BANK SURVEY

PART 13: RIGHT BANK CHARACTERISTICS

Type
Noncohesive ☐
Cohesive ☐
Composite ☐
Layered ☐
Even Layers ☐
Thick+thin layers ☐
Number of layers ___

Protection Status
Unprotected ☐
Hard points ☐
Toe protection ☐
Revetments ☐
Dyke Fields ☐

Bank Materials
Silt/clay ☐
Sand/silt/clay ☐
Sand/silt ☐
Sand ☐
Sand/gravel ☐
Gravel ☐
Gravel/cobbles ☐
Cobbles ☐
Cobbles/boulders ☐
Boulders/bedrock ☐

Layer Thickness
Material 1 (ft) ___
Material 2 (ft) ___
Material 3 (ft) ___
Material 4 (ft) ___

Ave. Bank Height
Average height (ft) ___

Ave. Bank Slope
Average angle (o) ___

Bank Profile Shape
(see sketches in manual)
___

Tension Cracks
None ☐
Occasional ☐
Frequent ☐
Crack Depth
Proportion of bank height ___

Distribution and Description of Bank Materials in Bank Profile

Material Type 1	Material Type 2	Material Type 3	Material Type 4
Toe ☐	Toe ☐	Toe ☐	Toe ☐
Mid-Bank ☐	Mid-Bank ☐	Mid-Bank ☐	Mid-Bank ☐
Upper Bank ☐	Upper Bank ☐	Upper Bank ☐	Upper Bank ☐
Whole Bank ☐	Whole Bank ☐	Whole Bank ☐	Whole Bank ☐
D50 (mm) ___	D50 (mm) ___	D50 (mm) ___	D50 (mm) ___
sorting coefficient ___	sorting coefficient ___	sorting coefficient ___	sorting coef. ___

Notes and Comments:-

PART 14: RIGHT BANK-FACE VEGETATION

Vegetation
None/fallow ☐
Artificially cleared ☐
Grass and flora ☐
Reeds and sedges ☐
Shrubs ☐
Saplings ☐
Trees ☐
Orientation
Angle of leaning (o) ___

Tree Types
None ☐
Deciduous ☐
Coniferous ☐
Mixed ☐
Tree species
(if known)
___
___
___

Density + Spacing
None ☐
Sparse/clumps ☐
dense/clumps ☐
Sparce/continuous ☐
Dense/continuous ☐

Roots
Normal ☐
Exposed ☐
Adventitious ☐

Location
Whole bank ☐
Upper bank ☐
Mid-bank ☐
Lower bank ☐

Diversity
Mono-stand ☐
Mixed stand ☐
Climax-vegetation ☐

Health
Healthy ☐
Fair ☐
Poor ☐
Dead ☐

Age
Imature ☐
Mature ☐
Old ☐

Height
Short ☐
Medium ☐
Tall ☐
Height (ft) ___

Lateral Extent
Wide belt ☐
Narrow belt ☐
Single row ☐

Notes and Comments:-

Bank Profile Sketches

Profile Symbols

Bank Top Edge	Failed debris	Engineered Structure
Bank Toe	Attached bar	Significant vegetation
Water's Edge	Undercutting	Vegetation Limit

PART 15: RIGHT BANK EROSION

Erosion Location
General ☐
Outside Meander ☐
Inside Meander ☐
Opposite a bar ☐
Behind a bar ☐
Opposite a structure ☐
Adjacent to structure ☐
Dstream of structure ☐
Ustream of structure ☐
Other (write in) ☐

Present Status
Intact ☐
Eroding:dormant ☐
Eroding:active ☐
Advancing:dormant ☐
Advancing:active ☐

Rate of Retreat
ft/yr (if applicable and known) ___

Rate of Advance
ft/yr (if applicable and known) ___

Interpretative Observations

Severity of Erosion
Insignificant ☐
Mild ☐
Significant ☐
Serious ☐
Catastrophic ☐

Extent of Erosion
None ☐
Local ☐
General ☐
Reach Scale ☐
System Wide ☐

Processes
Parallel flow ☐
Impinging flow ☐
Piping ☐
Freeze/thaw ☐
Sheet erosion ☐
Rilling + gullying ☐
Wind waves ☐
Vessel Forces ☐
Ice rafting ☐
Other (write in) ☐

Distribution of Each Process on Bank

Process 1	***Process 2***
Toe (undercut) ☐	*Toe (undercut)* ☐
Lower bank ☐	*Lower bank* ☐
Upper bank ☐	*Upper bank* ☐
Whole bank ☐	*Whole bank* ☐
Process 3	***Process 4***
Toe (undercut) ☐	*Toe (undercut)* ☐
Lower bank ☐	*Lower bank* ☐
Upper bank ☐	*Upper bank* ☐
Whole bank ☐	*Whole bank* ☐

Level of Confidence in answers (Circle one)
0 10 20 30 40 50 60 70 80 90 100 %

Notes and Comments:-

PART 16: RIGHT BANK GEOTECH FAILURES

Failure Location
General ☐
Outside Meander ☐
Inside Meander ☐
Opposite a bar ☐
Behind a bar ☐
Opposite a structure ☐
Adjacent to structure ☐
Dstream of structure ☐
Ustream of structure ☐
Other (write in) ☐

Present Status
Stable ☐
Unreliable ☐
Unstable:dormant ☐
Unstable:active ☐

Failure Scars+Blocks
None ☐
Old ☐
Recent ☐
Fresh ☐
Contemporary ☐

Interpretative Observations

Instability:Severity
Insignificant ☐
Mild ☐
Significant ☐
Serious ☐
Catastrophic ☐

Instability: Extent
None ☐
Local ☐
General ☐
Reach Scale ☐
System Wide ☐

Failure Mode
Soil/rock fall ☐
Shallow slide ☐
Rotational slip ☐
Slab-type block ☐
Cantilever failure ☐
Pop-out failure ☐
Piping failure ☐
Dry granular flow ☐
Wet earth flow ☐
Other (write in) ☐

Distribution of Each Mode on Bank

Mode 1	***Mode 2***
Toe ☐	*Toe* ☐
Lower bank ☐	*Lower bank* ☐
Upper bank ☐	*Upper bank* ☐
Whole bank ☐	*Whole bank* ☐
Mode 3	***Mode 4***
Toe ☐	*Toe* ☐
Lower bank ☐	*Lower bank* ☐
Upper bank ☐	*Upper bank* ☐
Whole bank ☐	*Whole bank* ☐

Level of Confidence in answers (Circle one)
0 10 20 30 40 50 60 70 80 90 100 %

Notes and Comments:-

PART 17: RIGHT BANK TOE SEDIMENT ACCUMULATION

Stored Bank Debris
None ☐
Individual grains ☐
Aggregates+crumbs ☐
Root-bound clumps ☐
Small soil blocks ☐
Medium soil blocks ☐
Large soil blocks ☐
Cobbles/boulders ☐
Boulders ☐

Vegetation
None/fallow ☐
Artificially cleared ☐
Grass and flora ☐
Reeds and sedges ☐
Shrubs ☐
Saplings ☐
Trees ☐

Age
Immature ☐
Mature ☐
Old ☐
Age in Years ☐

Tree species (if known)
___
___

Health
Healthy ☐
Unhealthy ☐
Dead ☐

Roots
Normal ☐
Adventitious ☐
Exposed ☐

Interpretative Observations

Toe Bank Profile
Planar ☐
Concave upward ☐
Convex upward ☐

Present Debris Storage
No bank debris ☐
Little bank debris ☐
Some bank debris ☐
Lots of bank debris ☐

Sediment Balance
Accumulating ☐
Steady State ☐
Undercutting ☐
Unknown ☐

Level of Confidence in answers (Circle one)
0 10 20 30 40 50 60 70 80 90 100 %

Notes and Comments:-

GUIDELINES FOR THE USE OF STREAM RECONNAISSANCE RECORD SHEETS IN THE FIELD

1. BACKGROUND

1.1 INTRODUCTION

The nature and causes of channel instability and sedimentation problems are often difficult to identify in the field. Even quite experienced river engineers and fluvial geomorphologists find it hard to describe the dominant forms and features of the valley, the channel and its sediments accurately. This is the case because channel stability problems may result from a wide variety of dynamic geomorphic processes, some operating at local scales, others at reach scales, and still others associated with instability of the entire fluvial system throughout the drainage basin.

In other cases, the channel is known to be stable, but channel improvements are essential for flood control or navigation purposes. It is then necessary to anticipate the geomorphic and sedimentary reaction of the channel to engineering works. This usually requires a thorough characterisation of the present, unmodified status of the system, based on field reconnaissance, measurement and observation.

The processes of sediment erosion, transport and deposition responsible for channel changes usually operate primarily during high flows and it is not usually possible to observe their operation directly. Any opportunity to observe the river at high flow should be taken, as invaluable insights into fluvial and sedimentary processes can be gained. However, often this simply is not possible.

Consequently, during a site visit, the appearance of the channel, its geomorpholgical setting and the sedimentary forms and features must be used to *infer* the types of processes operating during channel forming flows, and to judge the nature and severity of any related problems of channel instability. The state of the channel on any particular visit depends to some extent on the sequence of flow events responsible for significant erosion, sediment transport and deposition in the days, weeks, months and, sometimes, years prior to the visit. Also, the cyclical nature of some fluvial processes can produce a deceptive appearance of stability in a dynamically changing

channel. For example, continued bank erosion may occur by a cycle of flow under-cutting, geotechnical failure and basal clean-out. This can produce parallel retreat, with little apparent change in the appearance of the bank over time. Consequently, a channel bank may appear unchanged on consecutive visits to a site, even though it has retreated substantially between the two visits. This is the case if it is at about the same stage of toe clean-out when the visits are made, there having been one or more mass failures in between. At first it appears that the bank has not moved since the previous visit, the actual retreat only becoming apparent when the position of the bank relative to fixed points or baselines is re-established. If such reference marks are not available it is easy to under-estimate the severity of erosion and hence over-estimate the stability of the channel.

In conclusion, the form and features of the channel and its surroundings must be examined carefully if they are to yield reliable pointers to the true nature of the dominant flow and sediment processes, the impact of sediment related problems and the resulting state of channel stability or instability. Usually, the information necessary to make reliable estimates and interpretations is there, but the observer must know how and where to look for it.

1.2 OVERALL STRUCTURE OF THE SHEETS

The sheets are set out in five major sections, each starting on a new page. Each Section is divided into a number of Parts dealing with different aspects of the section. Each Part is sub-divided into a number of specific Topics. The main Sections are:

SECTION 1 - SCOPE AND PURPOSE puts the stream reconnaissance into the context of the problem being addressed and the purpose of the survey and it records the basic logistical information on when and by whom the survey was performed and notes the limits to the study reach covered in the survey.

SECTION 2 - REGION AND VALLEY DESCRIPTION deals with the regional scale. The aims are:

1. To define the geologic, geomorphic, landscape and human environment around the stream, particularly by establishing the nature of the river basin and the relationship between the river channel and its valley;

2. To identify any instability in the fluvial system in terms of its direction, severity and spatial extent. Reference is made here to vertical and lateral channel instability separately because it is vital at this early stage to identify whether the direction of channel instability is in the vertical plane, the horizontal plane, or both.

SECTION 3 - CHANNEL DESCRIPTION focuses on the stream channel itself with the aim of establishing a clear picture of the channel in terms of its characteristic dimensions, flow type, geologic or man-made controls on its vertical and lateral activity, the nature of the bed sediments, and the presence of sedimentary features such as islands and bars. These qualitative and semi-quantitative observations flesh-out the factual information provided by surveyed cross-sections and plan maps.

SECTION 4 - LEFT BANK SURVEY deals in greater detail with all aspects of bank assessment for the left bank. The aim is to establish a clear picture of the bank in terms of its characteristic geometry and materials, vegetation, erosion processes, geotechnical failure mechanisms, and state of toe sediment balance.

SECTION 5 - Right Bank Survey repeats the bank survey for the opposite bank and completes the reconnaissance record for a particular study reach.

1.3 APPLICATIONS OF THE RECONNAISSANCE SHEETS

The stream reconnaissance record sheets presented here are an attempt to provide some assistance in examining alluvial streams in the field. The sheets may serve different purposes for different individuals and applications. Six uses have been identified in preliminary testing and application of the sheets to date:

1. **Conducting Geomorphic Analyses of Streams** - In the context of a data collection and analysis project the sheets form part of the "Level 1 Geomorphic Analysis" described by Simons, Li and Associates (1982) or the "Reconnaissance Level Analysis" of Schumm et al. (1984). The record sheets are not intended as a substitute for conventional hydrographic, hydraulic and geotechnical surveys of the site. Rather they are a fore-runner of such surveys which are termed *Engineering-*

Geomorphic or Semi-Quantitative Surveys. Being made over a wider area, the reconnaissance level survey should allow any subsequent quantitative work to be better targeted on critical areas to increase efficiency.

2. **Supplying Input to Stable Channel Design Methodologies** - The sheets can be applied to gathering the descriptive data necessary to characterize existing channels, identifying the flow and sediment processes and mechanisms, and estimating the severity of any flow or sediment related problems. This is an important first step in the design of engineering works to improve channel stability and/or flood capacity. Only after these steps have been taken is it possible to determine the cause of the problems with any confidence and make sound recommendations concerning remedial measures.

New and innovative approaches to stable channel design such as the SAM modular method require input data of this type (Thomas, 1990). In this respect, the framework established here for characterizing the channel, its morphology and its sediments should be very useful in determining the applicability of the different equations for flow resistance, sediment transport and one-dimensional modeling. On this basis, the most appropriate quantitative equations to be used can be selected.

3. **In the Assessment, Modelling and Control of Bank Retreat** - The explanation, prediction and stabilization of bank retreat are all aided by the application of new approaches to the analysis of flow erosion processes and geotechnical failure (Thorne and Osman, 1988; Thorne and Abt, 1990; Hagerty, 1989). The input data and qualitative information necessary to apply such methods are collected in the course of using the stream reconnaissance sheets.

4. **As a Training Aide** - the sheets can be used in the training of staff who are inexperienced in field methods and techniques, but who are required to undertake stream reconnaissance (WES, 1990). The sheets are structured in a way which encourages a systematic and disciplined approach to the collection, recording and interpretation of both archive and field data. Use of the sheets helps the user to develop good practices which will benefit both the individual and the project. The sheets also help the user to decide where to look and what to look for when characterising channel forms and features.

5. **As an *Aide Memoir*** - Even experienced field personnel who do not need to use the sheets as a guide to conducting a reconnaissance survey may find them useful in structuring their time and effort and ensuring that no important aspects of the survey are accidentally omitted.

6. **To Establish a Historical Record of Stream Condition** - A reconnaissance trip is made at considerable cost in time, manpower and resources, but the observations, data and information gathered are not always permanently recorded and stored in any systematic fashion. Once the individuals actually undertaking the survey leave the office, it is extremely difficult for other staff to use the results of the survey effectively in subsequent work or projects. The record sheets provide a medium for the permanent record of the results of a stream reconnaissance trip, which may be filed for future reference. The sheets are also designed for ease of storage as a computerized database.

The sheets also have the potential to form the input data for a computerized expert system on the analysis of sediment related problems in river channels. To develop such a system is beyond the scope of the present project, but experience gained in the development and use of the reconnaissance sheets should be very useful should such systems be developed in the future.

2. GUIDELINES FOR COMPLETING THE SHEETS

2.1 INTRODUCTION

In this section detailed guidance is given on how to fill-out the Stream Reconnaissance Record Sheets in the field. References to particular sections, parts and topics that appear on the sheets are put in italics.

The sheets have been designed:

1. To produce a comprehensive record of the form, features and processes of the stream and;

2. To be applicable to a very wide range of types and sizes of river in diverse geographical, geological, geomorphic and land-use settings.

As a result they can appear detailed and overly long on first inspection. It should be remembered that in the great

majority of cases the answers to preliminary questions will mean that subsequent topics are inapplicable and this will simplify filling the sheets out considerably.

2.1.1 Expediency versus Completeness

Many engineers will be tempted to omit filling out some topics or whole sections because they feel that they are not justified by the scope of work of the project, or because, based on their level of experience with the river concerned, they are confident that the material is irrelevant. *This temptation should in most cases be resisted.* In fact, although there may be applications where it is expedient to omit sections and where there really is no need to look at the broader watershed features covered in Section 2, or at the detailed streambank descriptions of Sections 4 and 5, this is the exception not the rule. Also, omission of material seriously degrades the value of the stream reconnaissance as a historical archive record. Therefore, while provision is made in Section 1 to note that certain sections or topics have not been completed, some justification of the reason for omitting the material must be provided in the Notes and Comments.

Conversely, there will usually be justification for *customising* the sheets to a particular river, watershed or geographical region. This involves the removal of extraneous material rather than the omission of whole sections or topics. For example, if the study area lies entirely in a lowland sedimentary plain then references to mountains, bedrock, valley sides, coarse sediments such as boulders, and processes such as armouring have no bearing at all and may be edited out. The resulting slimmed-down sheets will still be comprehensive, but will also be simpler and more streamlined.

2.1.2 Filling-in the Sheets

When filling-in the sheets, there are two main types of response which may be recorded:

1. Topics where a box is ticked or ranked;

2. Topics where a numerical measurement is written in.

On the sheets, places where a tick or rank is required have boxes, while places where a numerical value is required have an under-lined space for the number to be written.

When ranking attributes (for example, the various types of vegetation present in the catchment (Part 1, Topic 6), or the different materials making up the bed of the stream (Part 7, Topic 1), it is suggested that the Braun-Blanquet Scale be used.

Table 1. Braun-Blanquet Scale of Ranking

Number of individual examples present and percentage cover of Reference Area	Recorded Rank
Any number and more than 75% cover	5
Any number and 50 to 75% cover	4
Any number and 25 to 50% cover	3
Any number and 5 to 25%	2
Numerous but less than 5% cover, or scattered with cover up to 5%	1
A few individuals covering a small area	+
A solitary individual covering a small area	r

The strength of this ranking system is that as well as recording the main types of cover making up most of the area, it also allows the observer to record the presence of rare or even individual examples that are seen to be significant, even though they cover only a small percentage of the area being described.

2.2 *SECTION 1 - SCOPE AND PURPOSE*

This section sets the context for the reconnaissance trip, records the details of when, where and by whom the surveys were carried out and provides space for notes and comments on general aspects of the trip.

Experience shows that a reconnaissance trip is usually more successful and the results are more worthwhile when it addresses a particular problem and has a clearly defined purpose. These should be agreed at the outset and entered on the sheet for future reference. It is also important to record the logistical details of the reconnaissance trip as these have a bearing on the results obtained. If any sections or topics are omitted this must be recorded and justified. All this information is entered on the front cover of the reconnaissance record sheets under section 1.

Finally, the level of detail required for the survey must be determined. This is deliberately left open so that the reconnaissance team can decide on how best to apply the sheets for their particular river, project and purpose.

The broad descriptions of the catchment and valley in Sections 1 and 2 may cover quite large areas and, possibly, describe the whole of a small catchment in one sheet.

However, the length of the reach of channel covered in Sections 3, 4 and 5 must be tailored to the situation, and the time and resources available.

At the most detailed level, the shortest meaningful reach would be of the order of 5 to 10 times the channel width in length. This would cover a single geomorphic unit of the river, such as an individual bendway or a pool-riffle pair in a single-thread channel, or a major bar-chute-complex unit in a braided channel. While the resolution of such a detailed survey would be excellent, many reaches would have to be surveyed to cover a significant length of channel. At the other extreme, a long stretch of river, within which the character of the channel did not change significantly, might be covered as a single reach if a lower level of detail was required. The length of the overall and sub-reaches should be recorded in Sections 1 and 3.

A useful compromise was found in surveying a 220 kilometer stretch of the right bank of the Brahmaputra River, Bangladesh. In the survey, which was made by boat, a continuous log was kept of the basic nature of the channel and bank, with notes being made of major changes of character. Typically, major changes occurred 15 to 20 kilometers apart, but with some closely more spaced variation around towns and bank protection structures. Between the points of change, short study reaches 0.5 to 2 kilometers in length were selected for detailed survey and a set of reconnaissance sheets was completed to represent that reach. Since the reach was entirely contained within the Ganges-Brahmaputra Delta, all references to uplands, valley sides, bedrock and coarse sediments were edited out to produce customised sheets for the particular application. In this way, overall coverage with local detail was achieved within the time and resources available.

2.3 *SECTION 2 - REGION AND VALLEY DESCRIPTION*

This section deals with the geologic setting, geomorphic features and sedimentary characteristics of the river channel and its valley. It is essential to establish these in order that sedimentation problems can be assessed in the context of the general river basin and sedimentary environment.

More particularly, it is important to establish any causal links between large-scale fluvial processes and local sediment impacts at the outset, and to identify the severity and extent of any underlying instability in the fluvial system. Often the particular problem to be addressed in an analysis, such as bank erosion or bed aggradation, is just a symptom of wider system instability and it should not then be treated in isolation if it is to be properly understood and dealt with.

Much of this section may be completed in the office by reference to topographic, geologic and land-use maps. However, it is still important to obtain an overview of the catchment and observe its physiography, vegetation and land-use directly. In large catchments, or where ground access is difficult, an over flight may be the best and most cost-effective way to achieve this.

The section is divided into 6 parts. Each is now dealt with in turn.

Part 1: Area around River Valley

This part has six topics. The aim is to characterize the surrounding land in terms of terrain, drainage pattern, geology, rock type, land-use, and vegetation.

Terrain defines the type of landscape within which the river valley is located. Generally, the greater the topography the more energy is available to do geomorphic work and the more rapid and pronounced will be terrain response to natural instability, or human-induced destabilisation.

Drainage Pattern defines the plan shape of the channel network. Eight common types of pattern have been identified (Howard, 1967) as indicative of the underlying terrain. These are shown in Fig. 1. and are described overleaf.

Drainage Patterns and Geologic Interpretations

Dendritic - homogeneous terrain, no strong geologic control

Parallel - A steep regional dip to the terrain

Trellis - Dipping or folded sedimentary rock

Rectangular - right-angled faulting and jointing

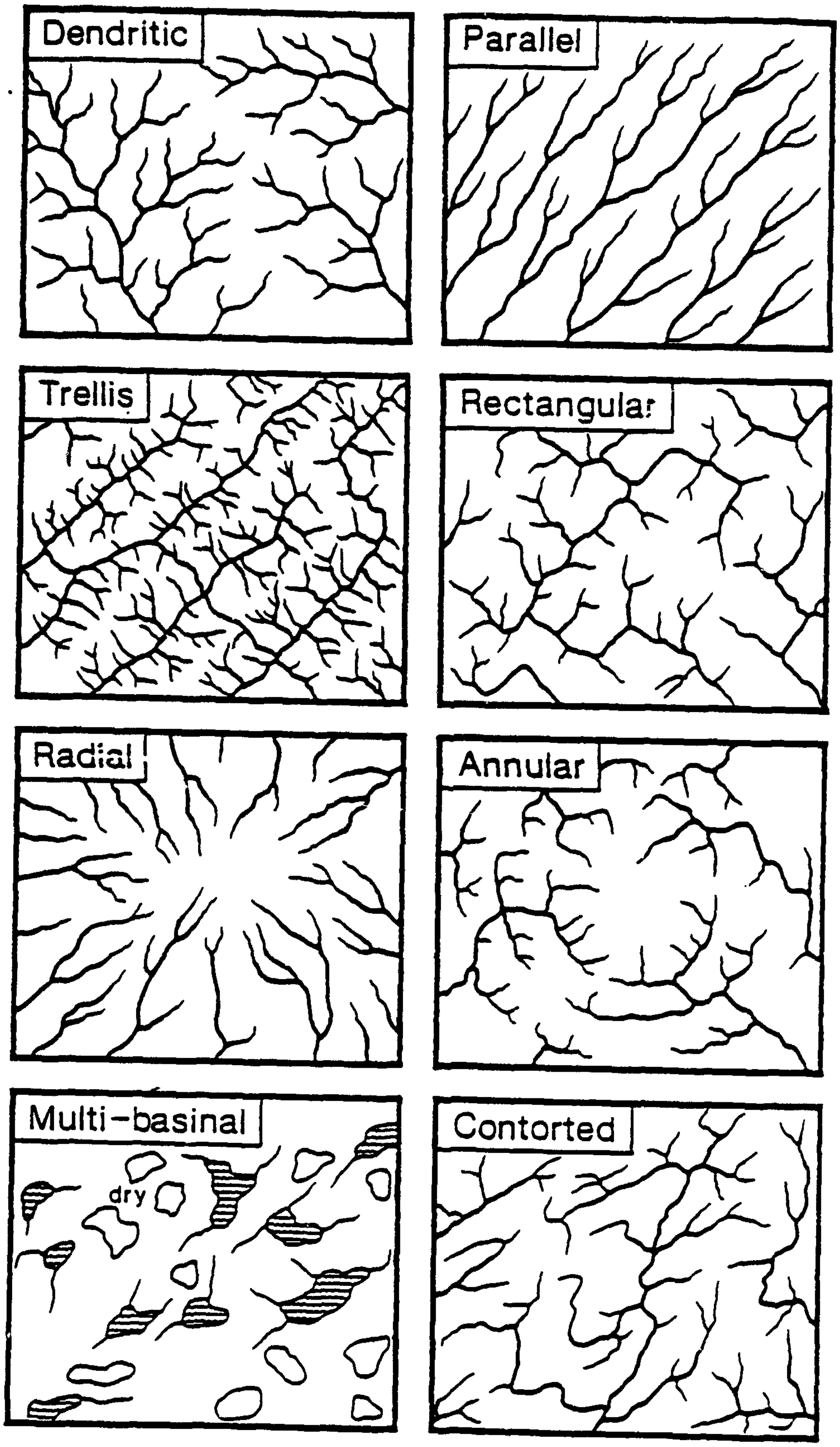
Radial - eroded structural domes or volcanoes

Annular - eroded domes or basins in layered rock

Multi-basinal - hummocky surficial deposits or limestone solution

Contorted - complex metamorphic structures

Figure 1. Basic Drainage Patterns (Adapted from Howard, 1967)



Surface Geology deals with the origin of the surficial materials making up the landscape. Erosion resistance is directly related to surficial geology and this will strongly affect the susceptibility of the area to geomorphic processes and related sediment impacts.

Rock Type defines the composition of the sub-surface materials. Erosion resistance and sediment yield (both volume and calibre) are also affected by the rock type.

Land-use addresses the type of human activity taking place in the area around the valley. Generally, cultivated areas have higher run-off potential and sediment yields than natural catchments. Urban and suburban catchments produce flashy run-off hydrographs and altered sediment yields.

Vegetation plays an important role in catchment hydrology, generating run-off and sediment yield. It is useful to know the vegetation community (or biome) in the catchment around the valley in order to gauge its influence on present catchment hydrology and sediment processes, and the potential for instability induced by changing vegetation or land-use.

Part 2: River Valley and Valley Sides

Has 9 topics. The aim is to define the form, scale, geometry, stability and mode of failure (if any) of the valley side slopes and the severity of any sediment related problems.

Location of River defines whether the river is in a valley or is located in some other physiographic setting such as on a fan, plain, delta or lake bed. If there are no valley sides then it is not necessary to complete the remainder of this section.

Valley Shape records whether the valley is symmetrical or asymmetrical. Asymmetrical valleys may have contrasting valley side characteristics and failures and these should then be noted separately.

Height and *Side Slope Angle* define the scale and geometry of the valley sides. The higher and/or steeper the valley sides, the greater the potential for them to be destabilized and to trigger system wide instability to the fluvial system.

Valley Side Failures records whether the slopes are stable, or prone to occasional or frequent failures. Valley wall failures indicate lateral geomorphic activity, and possibly valley widening.

Failure Locations indicates whether failures are adjacent to, or remote from, the river channel. This critically important because it determines the relationship between the river and the failures, and indicates how sediments derived from valley side failures are delivered to the river. Failures occurring away

from the river are not a direct result of river erosion. Sediments generated by such failures are stored at the base of the slope for long periods (these deposits are called colluvium by geomorphologists).

They then either make their way to the river by very slow processes, such as soil creep, or are eroded during catastrophic floods - which occur only rarely. These failures are uncoupled from the fluvial system. Conversely, failures adjacent to the river are coupled directly to river erosion. They are triggered by flow undercutting and deliver large volumes of debris directly into the channel. Such failures may be considered to be bank erosion at the largest scale and may pose serious problems in terms of system stability, land loss and wash load sediment yield.

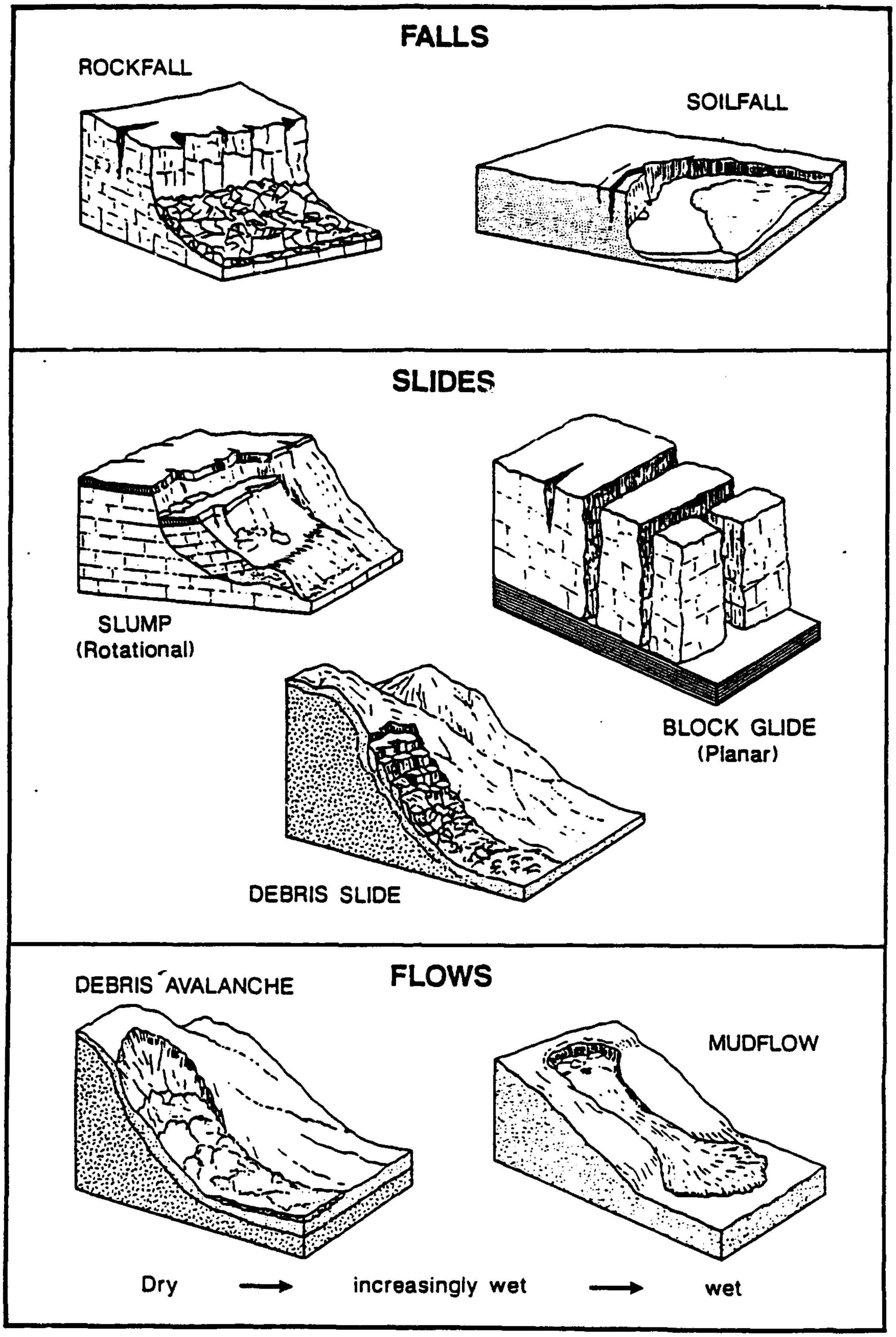
The last three sub-sections are in italics on the sheet to indicate that they are interpretative rather than being simple observations. Some degree of subjectivity is unavoidable in completing these sub-sections. To help to indicate how sure or unsure the user feels concerning the interpretations made here, the user can circle a level of confidence from 0 to 100% at the bottom of the section.

Material Type records the nature of the valley side materials as being either bed-rock, soil or unconsolidated debris. Debris is a superficial collection of broken rock.

Failure Type defines the mechanism of valley side failure. The type of failure determines the shape of the valley side after failure, controls the volume of material involved in each failure and may help to identify the cause of the instability. Sketches of typical failure modes are shown in Fig. 2.

Severity of Problems indicates the level of impact of valley side failures on the valley environment. Unstable valley sides pose serious hazards and can also be a major supplier of both coarse sediment and wash load to the fluvial system, causing serious local and downstream sedimentation.

Figure 2. Typical Valley Side Failure Modes (Developed from Varnes, 1958).



Part 3: Flood Plain (Valley Floor)

Has 8 topics. The aims are to characterise the presence, size and nature of the low-lying area between the valley sides and around the stream channel.

Valley Floor Type and *Valley Floor Data* note the presence or absence of a flat valley floor and its width in relation to the width of the channel. Rivers with fragmentary or narrow valley floors are closely coupled to hillslope run-off and erosion processes operating on the valley sides and are also liable to destabilization by valley side slope failures and sediment inputs. This is not true of rivers with broad flood plains. (Fig. 3 a and b).

Flow Resistance records the Manning's 'n' flow resistance coefficients for the left and right overbank areas. The 'n' values are used when calculating discharge capacity during out-of-bank floods.

Surface Geology deals with the origin of the surficial materials making up the flood plain. Erosion resistance is directly related to surficial geology and this will strongly affect the susceptibility of the area to fluvial erosion, channel shifting and related sediment impacts.

Land-use addresses the type of human activity taking place in the flood plain. Generally, cultivated areas require less engineering protection than urban or industrially developed flood plains. Urban and suburban catchments produce flashy, concentrated run-off, altered sediment yields and trash and debris which may impact channel stability.

Vegetation plays an important role in flood plain hydrology, hydraulics and sediment production. It is useful to know the type of vegetation assemblage in the flood plain in order to gauge its influence on present hydrologic, hydraulic and sediment processes, and the potential for instability induced by changing vegetation or land-use.

Riparian Buffer Strip and *Strip Width* note the presence and extent of a buffer of natural vegetation along the course of the river. The riparian corridor has long been known to provide important ecological habitat, but more recently it has been recognised that the riparian vegetation has other effects. First, it intercepts surface run-off and detains it, thereby reducing the potential for erosion by drainage over the bank edge. Second, it acts as a sink for pollutants in the surface and sub-surface run-off (thereby improving stream water quality). Third, it reduces near bank velocities, reinforces the bank material and limits access to the bank by grazing animals, all of which are

Figure 3. a) Upland river with a narrow flood plain and frequent coupling of channel and active erosion of valley side b) Lowland river with broad flood plain and uncoupled channel and hillslope processes.

a)

b)

beneficial to bank and channel stability. Experience shows that bank instability often occurs when the buffering effect of riparian vegetation is lost and cultivation extends right up to the bank top.

Part 4 Vertical Relation of Channel to Valley

This part has 11 topics. The aim is to establish the present relationship between the channel and its valley in terms of the vertical dimension, the dynamic nature of that relationship, and the existence of any features and landforms indicative of vertical instability.

Terraces are fluvial landforms produced by past vertical instability in the fluvial system. A terrace is a remnant of a former flood plain which is no longer subject to inundation (Fig. 4). It may be identified in the field as a strip of almost level ground higher than the present flood plain, and separated from it by a steeper slope. Terraces give the valley cross-profile a stepped appearance. They indicate that the river has had degradational instability in the past.

Number of Terraces records how many terraces may be identified. The theory of complex response shows how several terraces may be produced by a single destabilization of the system, as the river hunts for a new graded profile (Schumm et al., 1984). The number of terraces indicates the nature and magnitude of past vertical instability and demonstrates the potential of the system for dynamic vertical activity.

Trash Lines are found on the flood plain and in trees and bushes growing there. They are composed of floating trash and vegetation left after a flood and indicate the high water mark left by a flood event (Fig. 5a). The trash degrades quite quickly once it is lodged and so its condition acts as a guide to the time elapsed since the flood. If a fresh trash line is found above the elevation of the valley floor, and it is known that there has not been a catastrophic flood of long return period recently, this indicates that out-of-bank events occur fairly frequently, suggesting that the river is not incised significantly below its flood plain. Abundant trash lines left by floods of relatively short return period suggest that the river may be aggraded.

Overbank Deposits notes the presence and calibre of material deposited directly onto the valley floor by out-of-bank flow (Fig. 5b). The calibre of the sediment indicates the sediment transport competence of overbank flow. Deep, fast over bank flows are indicative of active flood plain processes, which are usually associated with an aggrading river.

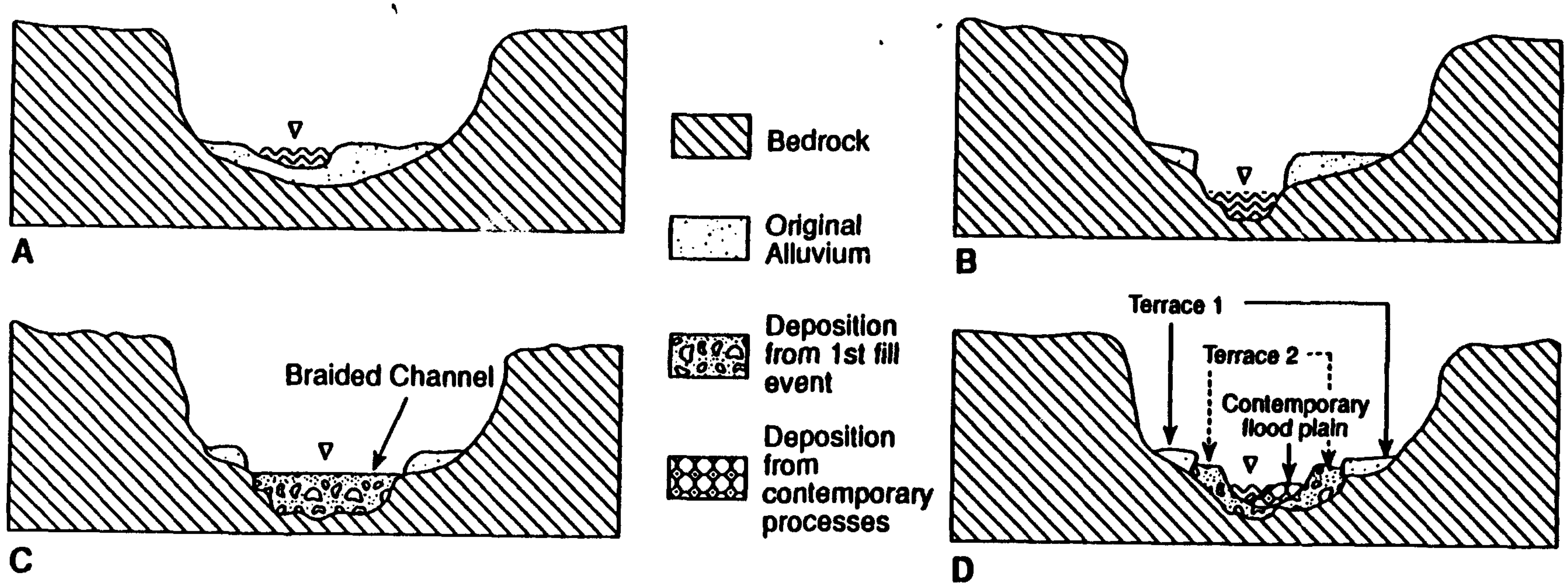


Figure 4. Terraces formed by past channel degradation and aggradation. A. Valley and alluvium with single-thread channel and flood plain. B. Channel degradation through alluvium and into bedrock leaves former flood plain as a terrace. Bank instability due to degradation leads to destruction of part of terrace. C. Aggradation generates inset alluvial fill as sediment supply increases due to bank instability and upstream degradation. D. - Second, lower terrace is formed when channel degrades slightly in response to reduced sediment supply due to bank stabilisation and establishment of graded long-profile. Lateral migration destroys part of lower terrace and forms new contemporary flood plain.

Figure 5. a) Trash line in tree and b) Over bank deposits: both are evidence of recent over bank events.

a)

b)

Levees and *Levee Description* deal with elevated banks above flood plain height and parallel to the course of the river. Natural levees are produced by overbank sedimentation during flood flows because the greatest amount of sediment tends to fall out of transport close to the river. Well developed natural levees indicate a river with a heavy load of sediment and frequent overbank flooding. Man-made levees are constructed to contain flood flows and protect the area behind them from inundation. They may be set back some distance behind the bank top. The presence of man-made levees indicates that the river is prone to frequent flooding in its natural state.

Levee Data and *Levee Condition* record the height, side slope angle and stability of any levees present.

The remaining 4 topics are interpretative and subject to a confidence level.

Present Status defines whether the channel in the study reach is presently adjusted to the valley floor elevation (graded) or whether it is either incised (entrenched), or aggraded (Fig. 6a and b). Incised rivers rarely flood, flow being concentrated in-channel except at extremely high discharges of long return period. They tend to have low width to depth (aspect) ratios and erode their banks through undercutting and mass failure. Aggrading rivers often flood, depositing sediment onto their flood plains and building levees. They have high aspect ratios, numerous bars and islands with a poorly defined channel, and widen through bank erosion by direct entrainment of bank material by the flow.

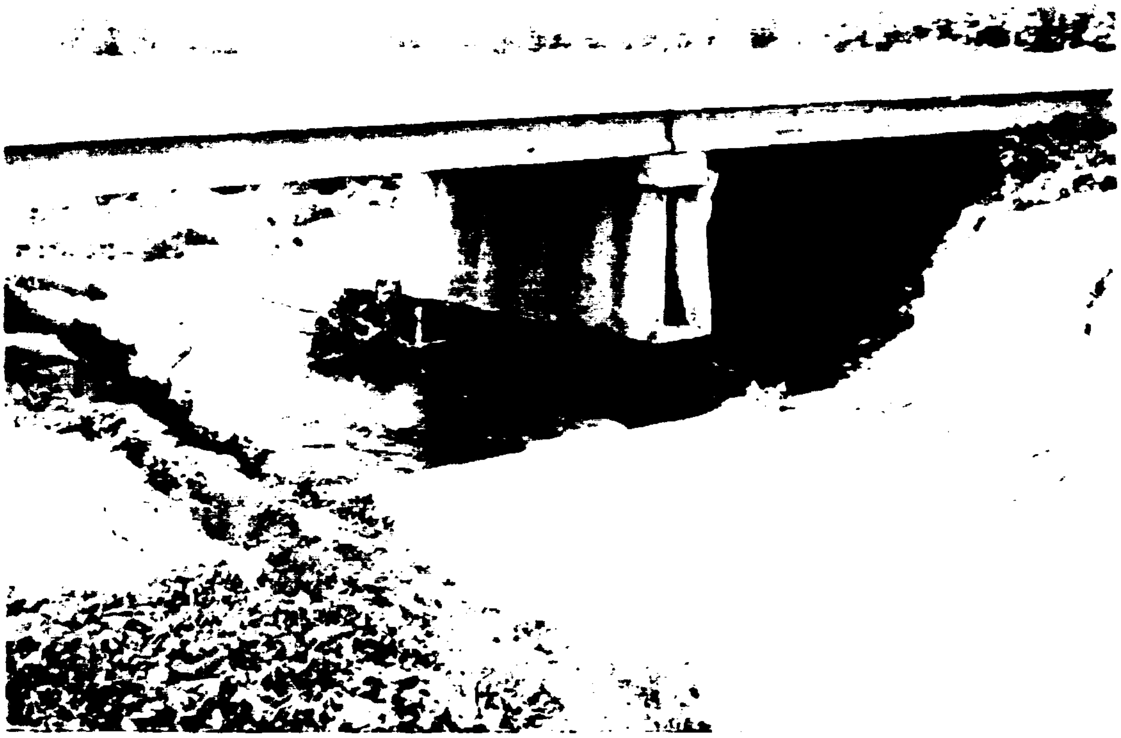
Instability Status defines whether vertical instability in the system is on-going or has ceased. Although the present status of the channel is important, to make predictions of future channel behaviour it is necessary to interpret the current trend of channel change as being either stable (no change), degrading (continued incision) or aggrading (continued siltation).

Problem Severity defines the severity of any current vertical instability. This helps to put any sediment impacts associated with aggradation or degradation into perspective and is a first step towards prioritising channel instability problems in terms of urgency of stabilization.

Problem Extent defines the scale of vertical instability in the river. Usually, this is an essential step in identifying the underlying cause of a channel instability problem. If a problem is common to the whole fluvial system then a local solution may be ineffective. For success, it usually necessary to match the scale of the solution to the scale of the problem.

Figure 6. Examples of: a) an incised river b) an aggraded river

a)



b)

Part 5: Lateral Relation of Channel to Valley

This part has 9 topics. The aim is to establish the present relationship between the channel and its valley in terms of the lateral dimension, the dynamic nature of that relationship, and the existence of landforms indicative of lateral instability and/or activity. Landforms include the planform geometry, type of planform evolution and the flood plain features.

Planform describes the geometry of the channel when viewed from above. It uses the generally accepted classification of rivers as being straight, meandering or braided (Fig. 7). For single thread channels, sinuous channels are in the transition between straight and meandering. They have alternate bars and cut-banks opposite leading to curved flow, but have not yet attained a truly meandering course. Irregular meanders lack the symmetry of regular, or classical, meanders and usually indicate that the planform is being influenced by outcrops of erosion resistant materials in the banks. Tortuous meanders are highly convoluted and experience neck cut-offs. Braided rivers are very wide and shallow with multiple sub-channels (anabranches) due to divided flow around braid bars.

Planform Data records the characteristic dimensions of any meanders (Fig. 8). Bend radius measures the tightness of the bend in terms of the radius of a circle approximately following the channel centerline. Meander belt width is the width of the strip of flood plain regularly swept by the channel as bends migrate downstream. Wavelength is twice the long valley distance between crossings (meander inflection points). Meander sinuosity is the channel length divided by the straight line valley length between crossings.

Lateral Activity records the type of channel planform evolution currently taking place (Fig. 9). Meander progression (down valley movement of the bend) occurs when bank erosion in meander bends is concentrated at the outer bank between the bend apex and the downstream crossing. Increasing amplitude occurs when the meander grows laterally as well as progressing downstream. In mature, meandering rivers progression leads to some bends being destroyed by neck and chute cut-offs. Irregular erosion occurs where variability (for example, due to local contrasts in flood plain sediment erodibility) disrupts the regular pattern of lateral activity. An avulsion is the rapid abandonment of the river's historic course in favor of a new course. Avulsions usually occur during floods. Braiding occurs by apparently random shifting of sub-channels (anabranches), to produce impinging flow, intense local bank erosion and a dynamic, unpredictable plan shape to the bank lines.

Figure 7. Guide to classification of river channel planforms

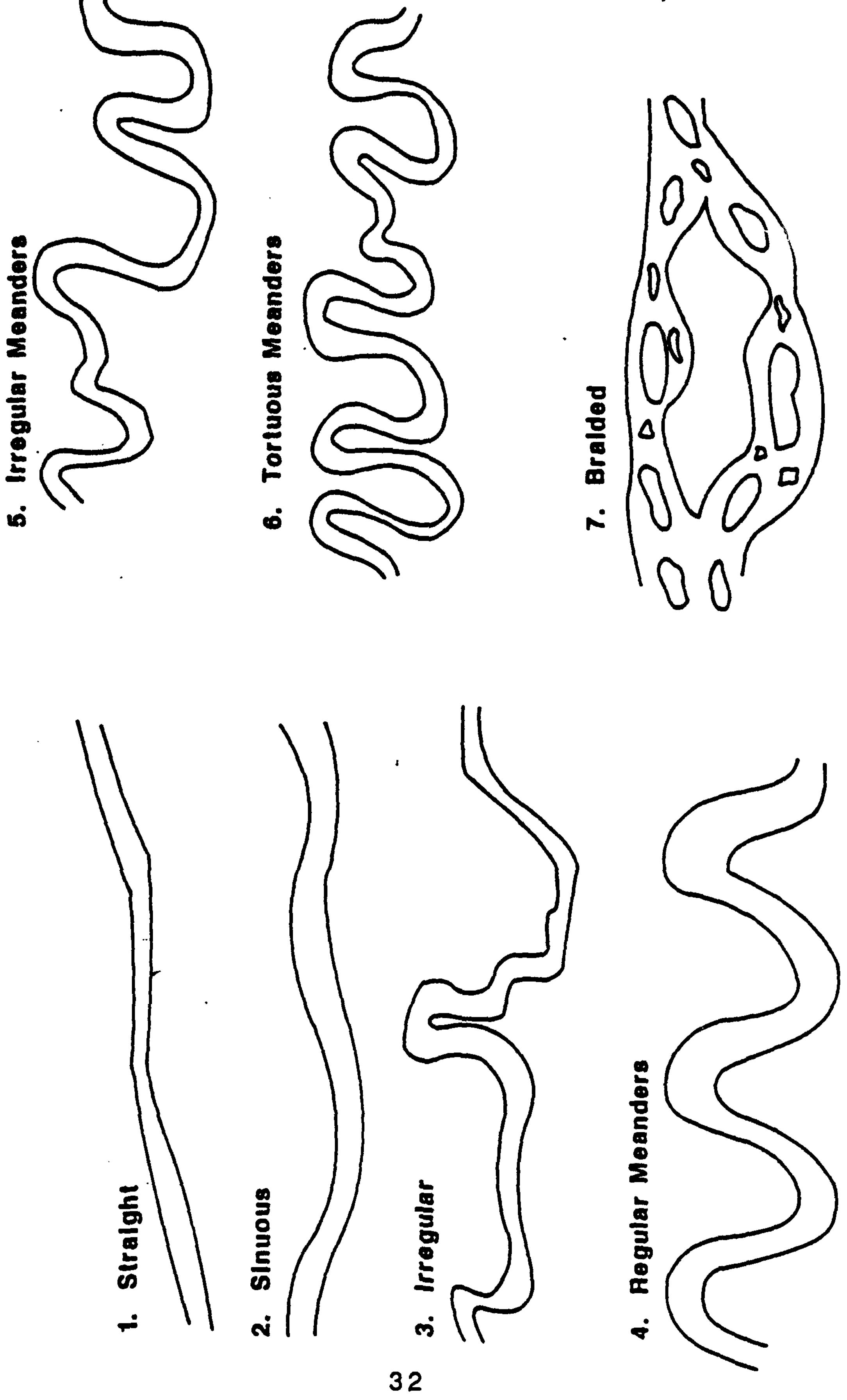
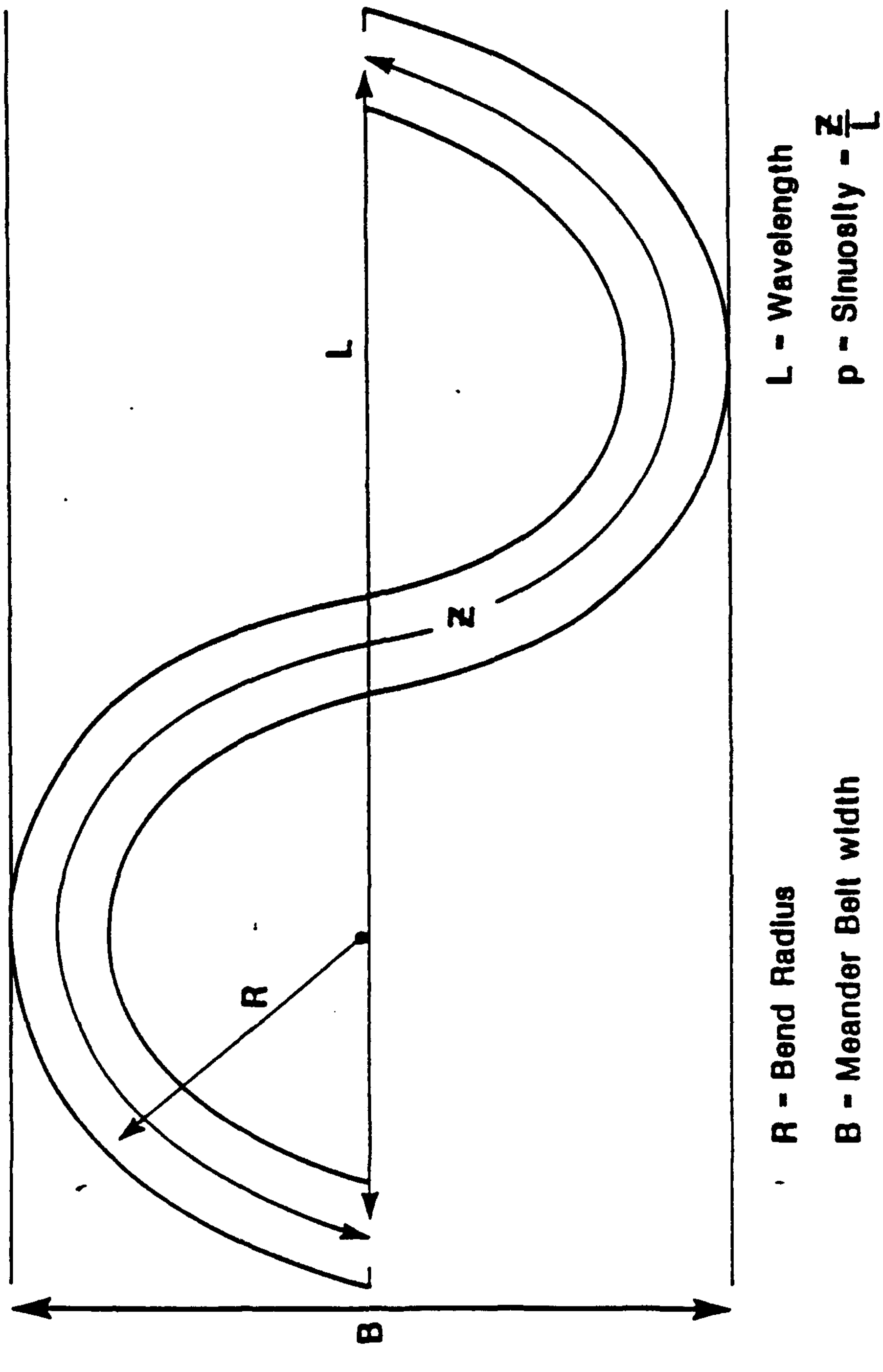


Figure 8. Definition of meander planform parameters



Flood Plain Features are associated with different types of lateral activity (Fig. 9). Meander scars are steep scarp slopes left in the flood plain by meander progression. Scroll bars are low, curved ridges in the flood plain which are found inside and parallel with meander loops. Swales or sloughs are low troughs running between the scrolls. Bars and swales are produced by point bar migration on the advancing, convex bank, during meander growth through increased amplitude. Oxbow lakes are crescent-shaped lakes which were once part of a meander but which were cut-off and abandoned due to meander progression. Abandoned channels are unsilted reaches of the channel left behind after an avulsion. Braided deposits give the flood plain an uneven, hummocky topography, with frequent abandoned channels, vegetated braid bars and sloughs.

The remaining 4 topics are interpretative and subject to a confidence level.

Present Status defines whether or not the channel width is adjusted to the present flow regime. Adjusted channels have stable widths over time, although they may still be laterally active if they erode one bank and deposit sediment at the other (Fig. 10a). This is termed 'dynamic equilibrium'. Over-wide rivers are broad and shallow with shifting bars. They have stable banks and accumulated sediment shelves at the toes of both banks, producing a composite, "two-stage channel" type of cross-sectional shape (Fig. 10b). Narrow rivers have low aspect ratios, active erosion of both banks, no sediment stored at either bank toe and more trapezoidal cross-sections (Fig. 10c).

Instability Status defines whether lateral instability in the system is on-going or has ceased. Although the present status of the channel is important, to make predictions of future channel behaviour it is necessary to interpret the current trend of channel change as being either stable (no change), widening (continued erosion of both banks) or narrowing (continued deposition at both banks).

Problem Severity defines the severity of any lateral instability. This helps to put any sediment impacts associated with bank line movement and lateral shifting into perspective and is a first step towards prioritising channel instability problems in terms of urgency of stabilization.

Problem Extent defines the scale of lateral instability in the river. Usually, this is an essential step in identifying the underlying cause of an instability problem. If a problem is common to the whole fluvial system then a local solution may be ineffective. For success, it usually necessary to match the scale of the solution to the scale of the problem.

Figure 9. Types of lateral activity and typical associated flood plain features

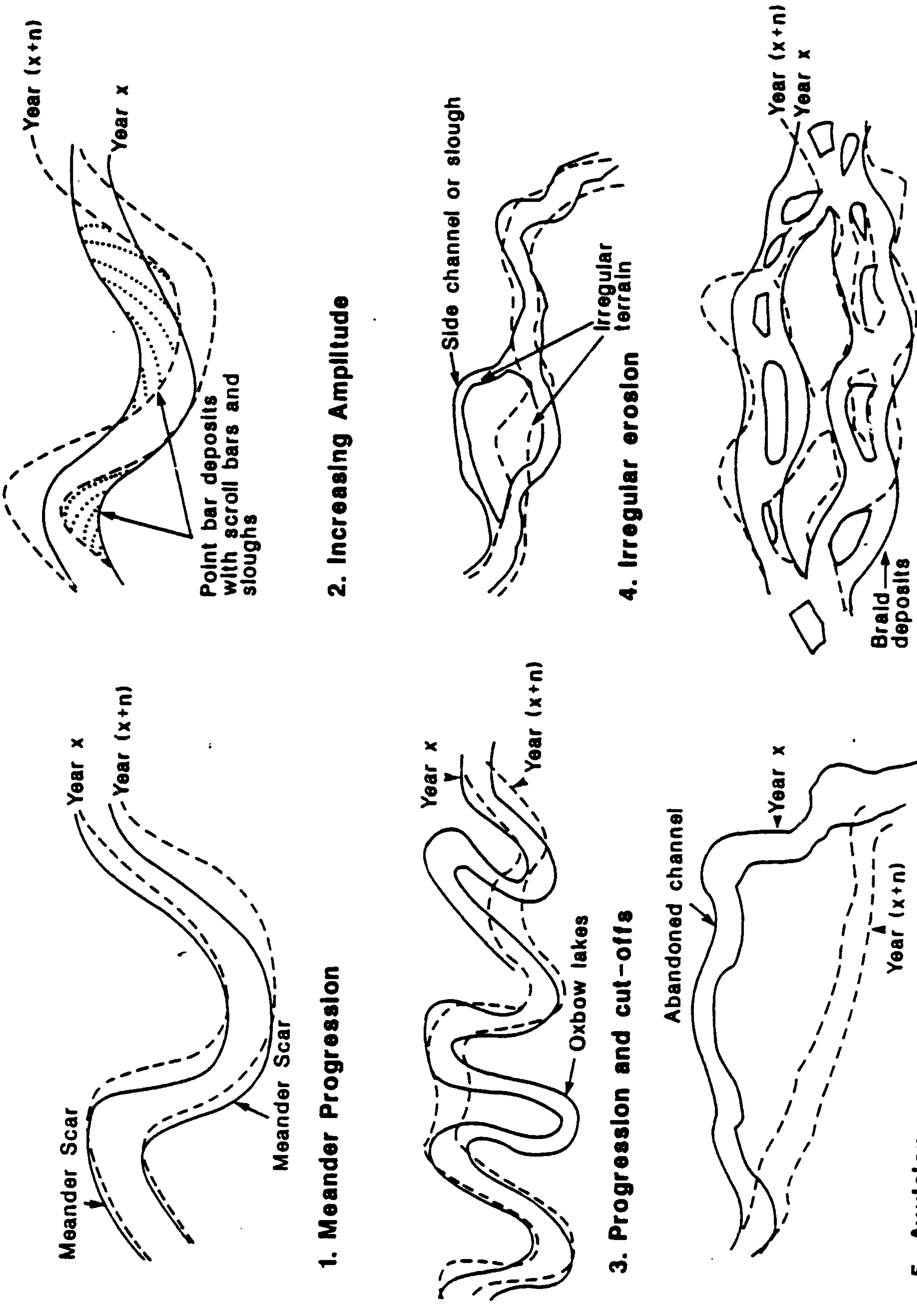


Figure 10. Examples of: a) a shifting river in dynamic equilibrium, b) an over-wide channel, and c) a channel which is too narrow

a)

b)

c)

2.4 SECTION 3 - CHANNEL DESCRIPTION

This section deals with the geomorphic features and sedimentary characteristics of the river channel. It is essential to establish these in order that the channel can be characterised and classified correctly.

There are causal links between the erosion and deposition processes operating on the bed and banks. It is artificial to view either the bed or banks in isolation. The related features of the bed and banks may be used to help identify the nature, severity and extent of any underlying instability in the fluvial system. Also, they can help indicate the sensitivity of the channel to destabilization through unsympathetic engineering.

The section is divided into 2 parts. Each is now dealt with in turn.

Part 6: Channel Description

This part has 6 topics. The aims are to characterize the channel in terms of its dimensions, flow regime and geologic, sedimentary or man-made controls on bed scour and bank retreat. This supplies the basic information needed by an engineer or geomorphologist to represent the river and its channel in terms of basic hydraulics and potential instability.

Dimensions gives an approximate guide to the size and shape of the channel in terms of the standard hydraulic geometry parameters of average top bank width, average water surface width on the day of observation, average channel and water depths, reach slope, estimated mean velocity, and the Manning's 'n' coefficient for in-bank flows. Overbank 'n' values were covered in Part 3 "Flood plain (Valley Floor)".

Flow Type defines the regime of flow in the channel according to the principles of free surface flow (Fig. 11). Uniform/Tranquil flow lacks major changes in flow velocity with distance along the channel and is sub-critical. Uniform/Shooting flow lacks major changes in flow velocity along the channel and is super-critical. Pools and riffles are alternating bed features producing non-uniform flow. Pools are areas of deep, slow flow with a gentle water surface slope. Riffles are areas of shallow, fast flow with a steep water surface slope. Steep + Tumbling flow occurs in high gradient streams with coarse bed material which disrupts the water surface and produces local super-critical flow between and over boulders. Steep + Step/pool flow is found in very steep channels with boulders arranged in periodic steps across the channel and plunge pools in between.

Figure 11. Types of flow in natural rivers. a) Uniform tranquil; b) Pool and Riffle; c) Tumbling/Step-Pool

a)

b)

Bed Controls set limits on the degree of vertical instability allowed by the local geology, materials and/or human intervention. A control is a feature which is not easily eroded by the river, thereby preventing continued instability.

Control Types defines the nature of the bed controls (Fig. 12). Natural examples are bed rock outcrops, coarse sediments which form an immobile armor layer, and fine sediments which are strongly cohesive. Where natural controls like these are absent, weirs or cut-off walls may be constructed to prevent bed degradation. Such *grade control structures* are vital where severe degradation is occuring and natural controls are either absent or unreliable. Foundations and protection constructed at bridges and culvert crossings may also act as bed controls.

Width Controls set limits on the degree of widening and/or lateral migration allowed by the local geology, materials and human intervention. A control is a feature which is not easily eroded by the river, thereby preventing continued bank line retreat.

Control Types define the nature of the width controls (Fig. 13). Natural examples are bed rock outcrops, coarse sediments which form an immobile armour on the bank, and fine sediments which are strongly cohesive. Controls due to fine sediments are often associated with clay plugs and back swamp deposits in the flood plain left by earlier depositional activity. Where natural controls like these are inadequate, dyke fields and/or revetments may be used to control river width and bank line movement Such *training structures* are a vital part of bank protection schemes in systems where width is unstable and natural controls are either absent or unreliable.

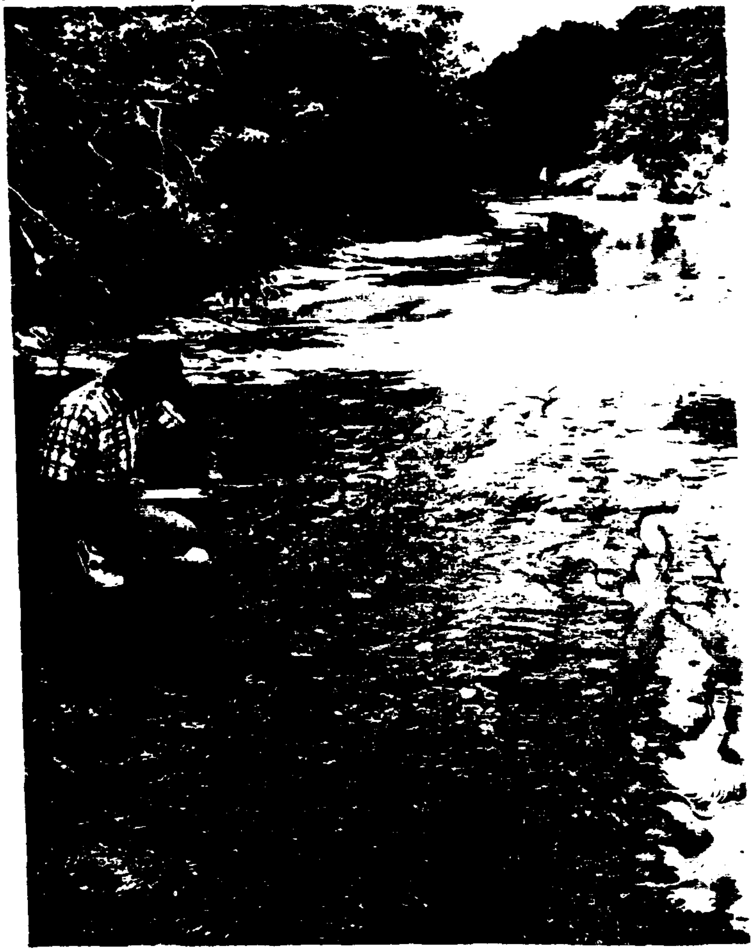
Part 7: Bed Sediment Description

This part has 10 topics. The aims are to characterize the sediments in the bed and bars of the channel in terms of their types, stratigraphy, depth, size distributions, bed forms and bar types. This supplies the basic sediment information needed by an engineer or geomorphologist when calculating sediment transport and potential bed instability.

Bed Material describes the bed sediment of the river. This is important because there are fundamental differences in the flow and sedimentary regimes and types of sediment related problems of rivers with clay, silt, sand, gravel or boulder beds.

Figure 12. Types of bed control in rivers. a) Bedrock; b) Boulders; c) Gravel armour; d) Cohesive materials; e) Bridge protection; f) Grade control structure

a)



b)

c)

d)

e)

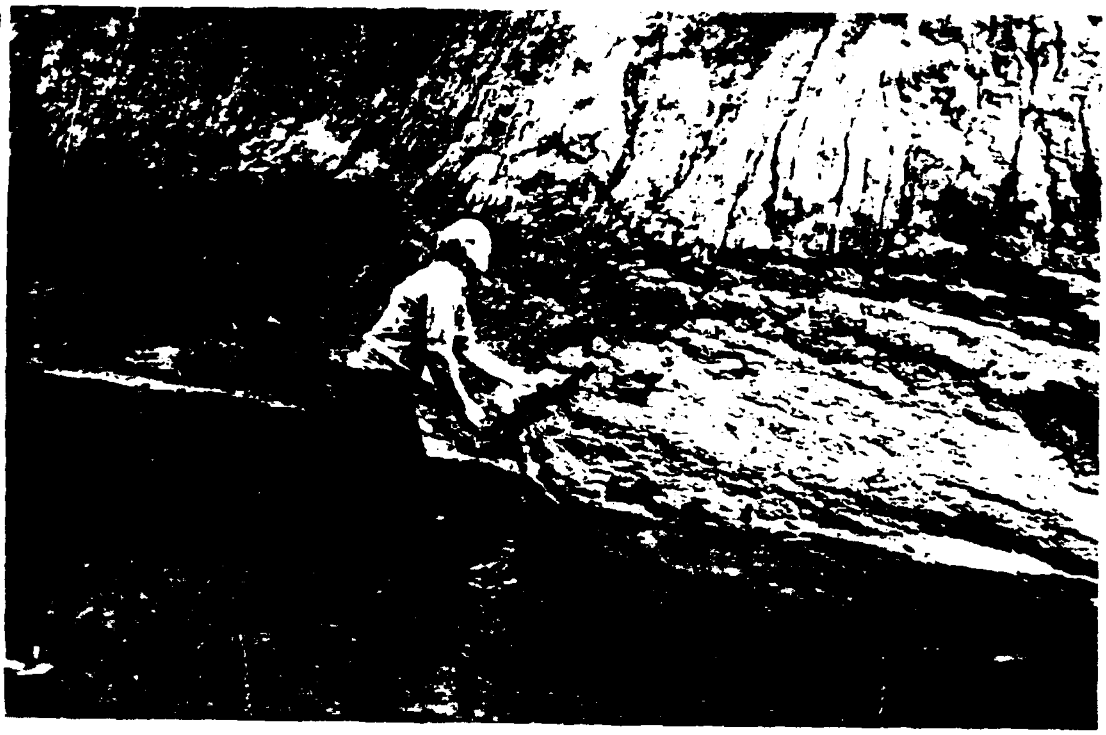
f)

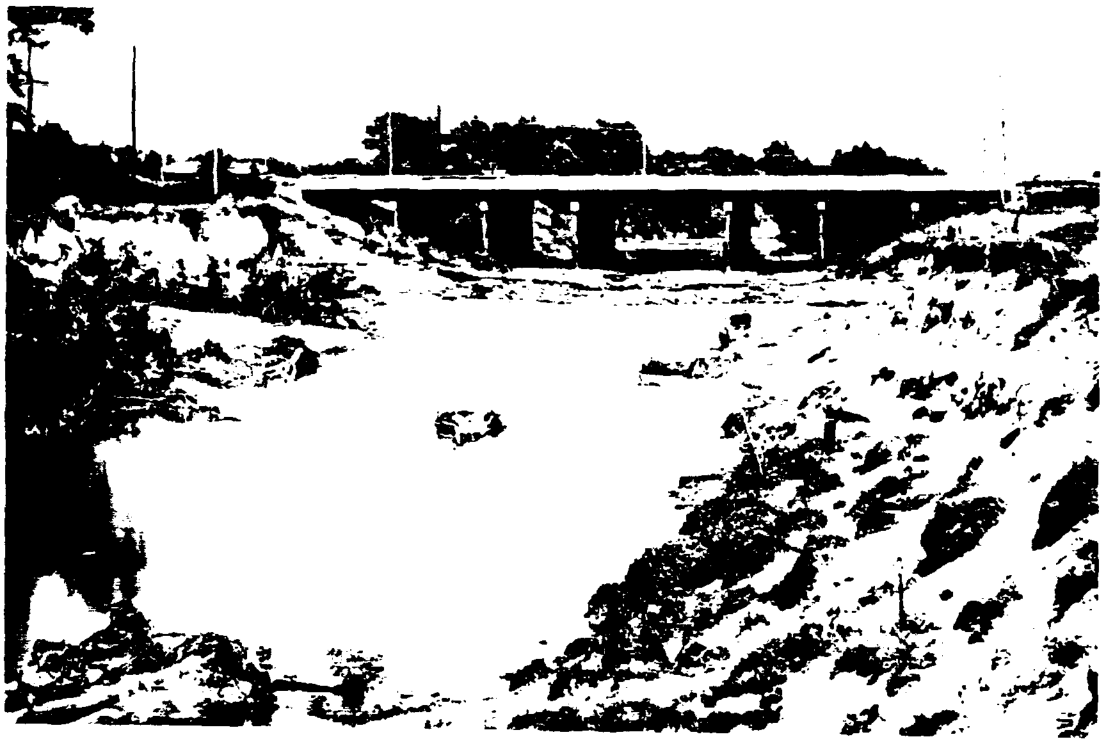
Figure 13. Types of width control in rivers. a) Bedrock; b) Revetment; c) Cohesive materials d) Bridge abutments. For boulders, gravel armour and dykes/groynes see Figs. 12b, 12c and 19d, respectively

a)

b)

c)





d)

Bed Armor identifies whether a coarse surface layer is present (Fig. 14). An armor layer limits the availability of bed sediments for transport and the potential for bed scour. Two types of armor have been identified: static armor is much coarser than the underlying sediment and is immobile under all but catastrophic flood flows; mobile armor is a little coarser than the underlying sediment and is moved by moderate events below bankfull flow.

Sediment Depth records the depth of loose sediment in the bed of the channel. This gives a guide to the size of the reservoir of sediment stored in the channel and available for transport by the flow. Degrading channels have thin bed sediment thicknesses, aggrading channels have thick layers.

Surface and Substrate Size Data are quantitative data based on sieve or size-by-number analyses of bed material samples taken at a representative point in the bed. This should be at about mid-channel in a crossing, away from obvious bar and island features. A separate substrate sample is only necessary if an armor layer is present. Techniques for sampling and analysing bed sediments are described in most rivers texts. <u>Note</u>: It may not always be necessary to measure bed material sizes quantitatively:qualitative description (in 'Bed Material') may be sufficient, depending on the purpose of the survey.

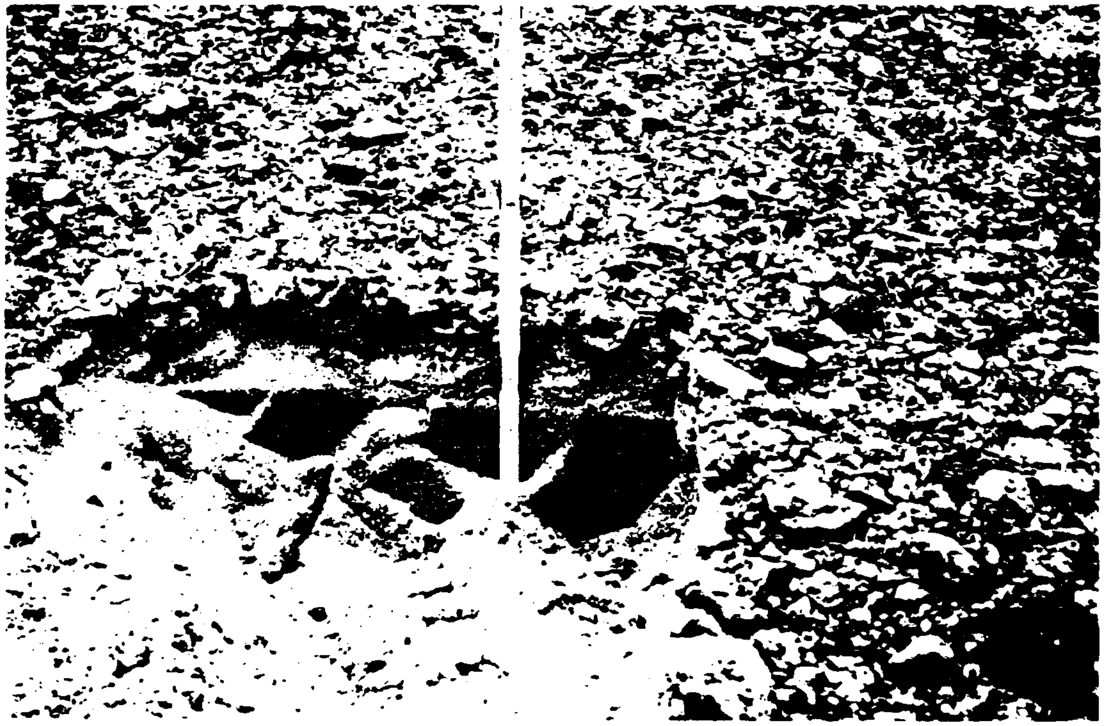
Bed Forms (Sand) notes the presence and type of bed forms in sand-bed channels. Bed forms are very important in producing form roughness which increases the Manning's 'n' for the channel and play a dominant role in the movement of bed load. Bedforms on this scale are not usually present in gravel-bed rivers.

Islands or bars accounts for macro-scale bed features and the presence of divided reaches in the flow. Islands and bars can have important impacts on flow resistance, channel capacity and in-channel sediment storage. Divided flows are generally less hydraulically efficient than single channel flows.

Bar Types describes the shape (morphology) of any bars (Fig. 15). Bars represent major topographic features in the channel bed and are intimately related to flow patterns and sediment transport distributions. They may be responsible for diversion of the flow so that it attacks one or both banks, promoting bank erosion, toe scour and bank line retreat.

Bar Surface and Substrate Data are quantitative data based on sieve or size-by-number analyses of bar material samples taken at a representative point in the bar. This should be at about mid-bar, away from obvious bar-head and bar-tail materials. A separate substrate sample is only necessary if an armor layer is present. Bars are often the primary source of sediment for transport by the river, especially in rivers with

Figure 14. Armor layer in a gravel-bed river



armored beds. Bar samples may be taken to indicate the approximate size distribution of the high flow sediment load.

Channel Sketch Map and Representative Cross-section are spaces provided for a visual representation of the channel in the study reach. An example for a reach of the Snake River, Wyoming is shown in Fig. 16. The aims are to show the shape and features of the channel and record the sampling points for bed and bar sediment samples. Also, photographs showing: i) views upstream and downstream along the study reach ii) right and left banks, and iii) special features of the channel should be taken and photo points and orientations marked on the map so that they can be relocated and repeated precisely in any future re-surveys. This greatly enhances their value as a guide to bed scour, bank erosion, channel changes and system instability. Fig. 17 shows examples of site photographs from the study reach on the Snake River.

Figure 15. Bar type classification

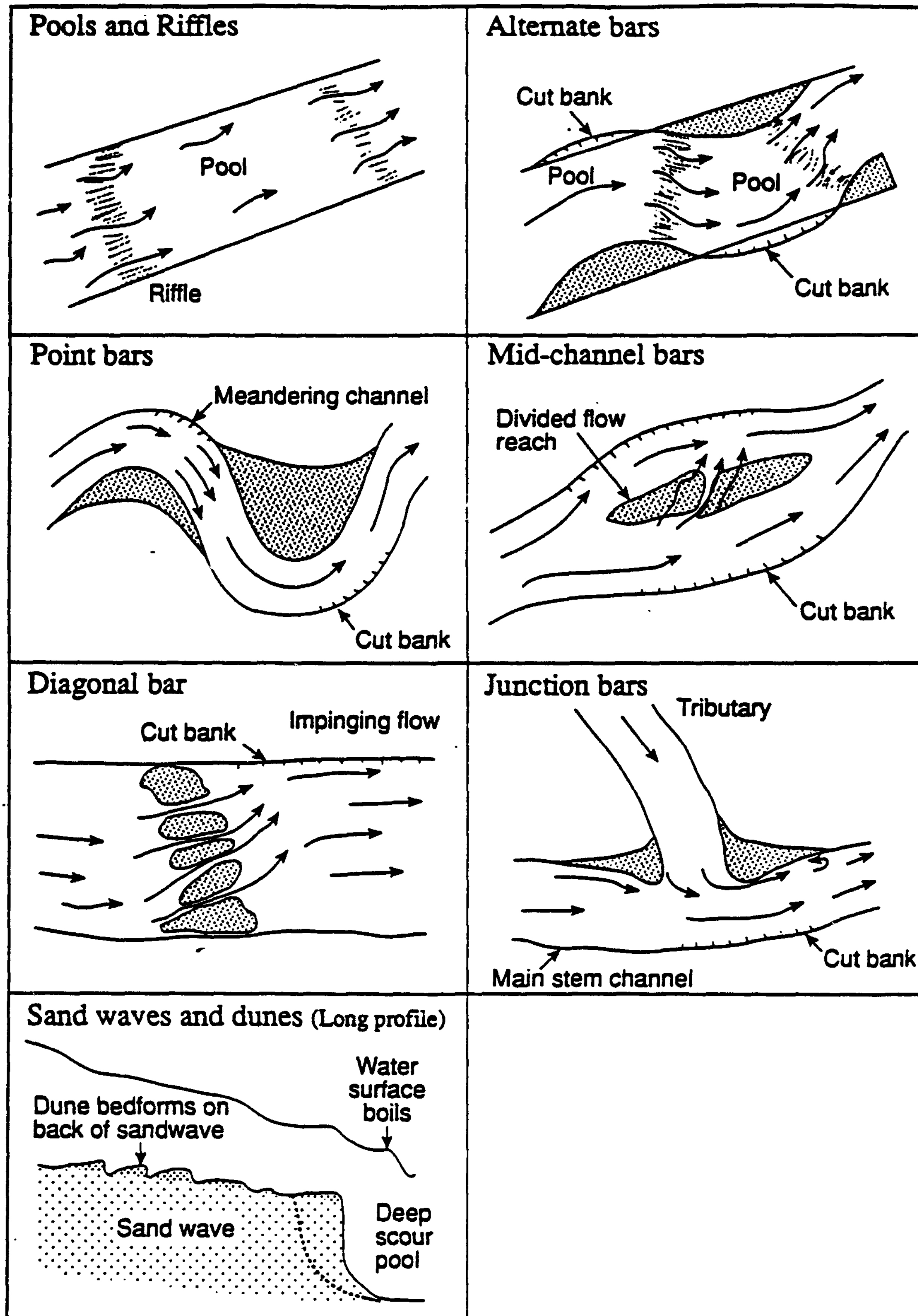


Figure 16. Example sketch map and representative cross-section: Snake River near Jackson Hole, Wyoming

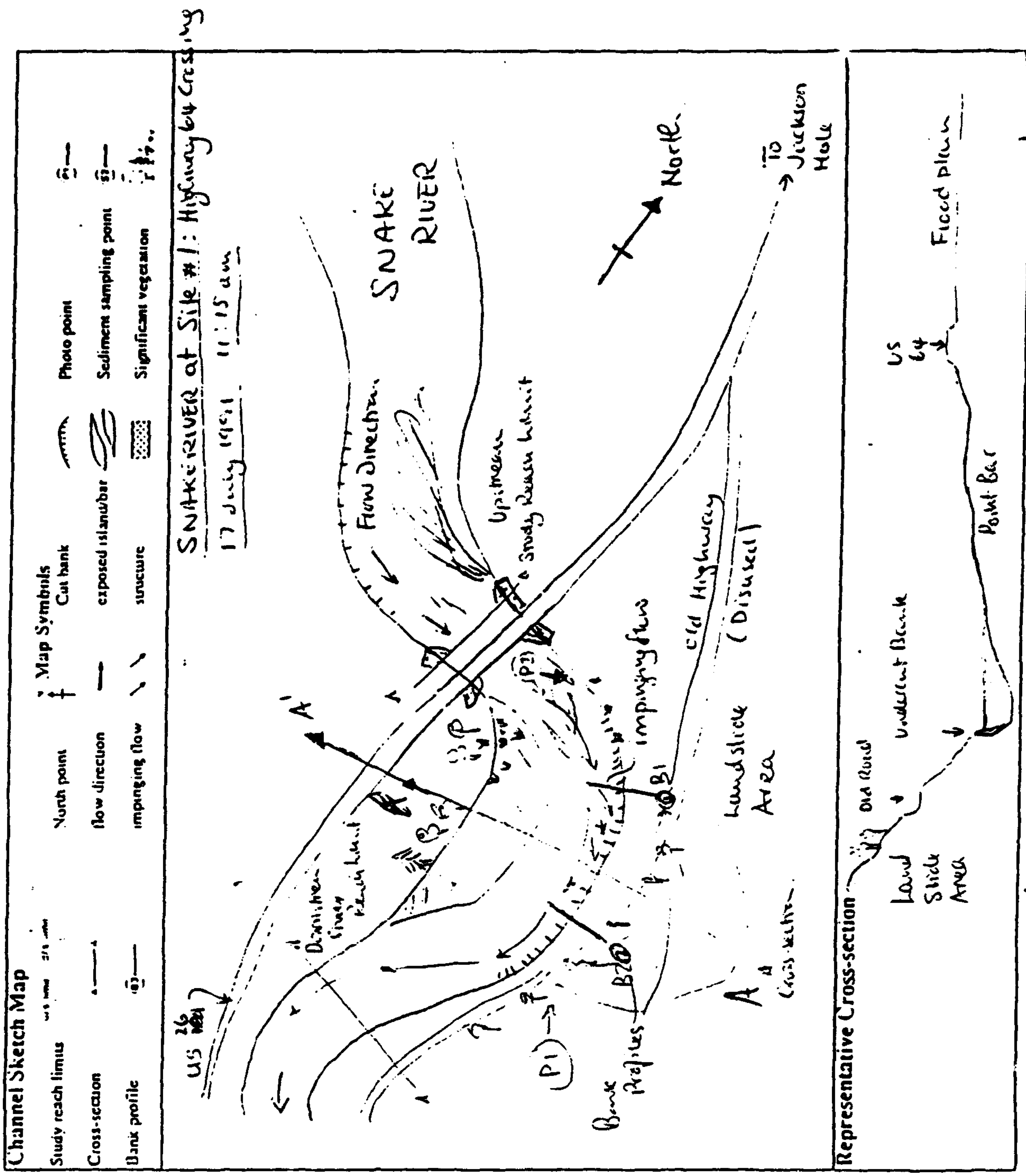


Figure 17. Example site photographs: Snake River near Jackson Hole, Wyoming. a) P1, view upstream over site, b) P2, view of under-cutting and sliding of valley side

2.5 SECTION 4 - LEFT BANK SURVEY

This section describes in detail the character, vegetation, erosion processes, geotechnical failure mechanics and toe-sediment balance for the left bank. It is divided into 5 parts, dealing with each of these aspects in turn. A complete and thorough evaluation of the bank and its dynamics lies at the heart of the field inspection and forms the basis for the explanation of bank line retreat and the selection of appropriate approaches to modeling channel processes and designating stabilization strategies.

It is important that the user complete each part independently of the information gathered in other parts. For example, the status of bank stability with regard to mass failure is not addressed until Part 11. Users should not allow the presence or absence of failures influence their selections in Parts 8 to 10 which do not deal with bank failures, but with other bank characteristics and bank erosion processes.

The accumulation of bank failure debris and sediment at the toe of the bank is a very significant and important morphological feature of alluvial channels. Consequently, it is dealt with in Part 12, separately from the intact bank.

Part 8: Left Bank Characteristics

This part contains 13 topics. The aim is is characterize the left bank in terms of its type, materials, protection status, approximate dimensions, shape and degree of cracking. All of these characteristics are of fundamental importance to bank erosion, failure and stabilization.

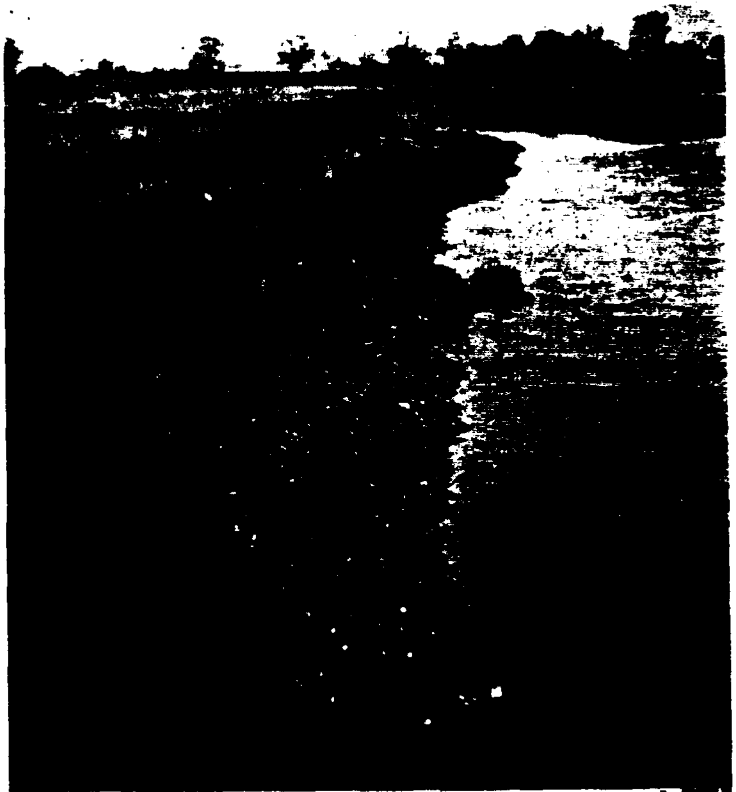
Type establishes the overall classification of the bank as being noncohesive, cohesive, composite or layered (Fig. 18). There are basic differences between banks formed in different materials, or combinations of materials. Noncohesive banks are formed in sands, gravels, cobbles and boulders that lack intrinsic cohesion. Cohesive banks are formed in silts and clays which are cohesive. Composite banks consist of a single cohesive layer underlain by a single noncohesive layer. Such banks are common in rivers with noncohesive bed material (sand or gravel) which are flowing through alluvial flood plain deposits consisting of bed material overlain by overbank fines. Layered banks consist of layers of noncohesive and cohesive materials laid down during a past aggradational phase. Often the layers are of uneven thickness and this can be very significant to bank erosion and hydrology.

Figure 18. Bank Types: a) Noncohesive; b) Cohesive; c) Composite; and d) Layered

a)

b)

c)



d)

Protection Status establishes whether the bank is unprotected or has been subject to engineering stabilization (Fig. 19). Where a bank has been protected the condition and effectiveness of the structure should be described in the *Notes and Comments* space.

Bank Materials details the composition of the bank in terms of the characteristic types of sediment for up to four materials making up the bank. This supplies information on the nature of the bank materials for interpreting bank erosion and failure processes and the type of material input to the fluvial system.

Layer Thickness records the thickness of each stratigraphic unit making up the bank.

Mean Bank Height and Mean Bank Slope record the approximate overall height and steepness of the bank. Both are important in determining the geotechnical stability.

Bank Profile Shape augments the height and slope data by specifying the form of the bank profile. This can be a good indicator of the dynamic nature of current bank retreat, stability or advance. Typical bank profiles and their interpretations are shown in Fig. 20.

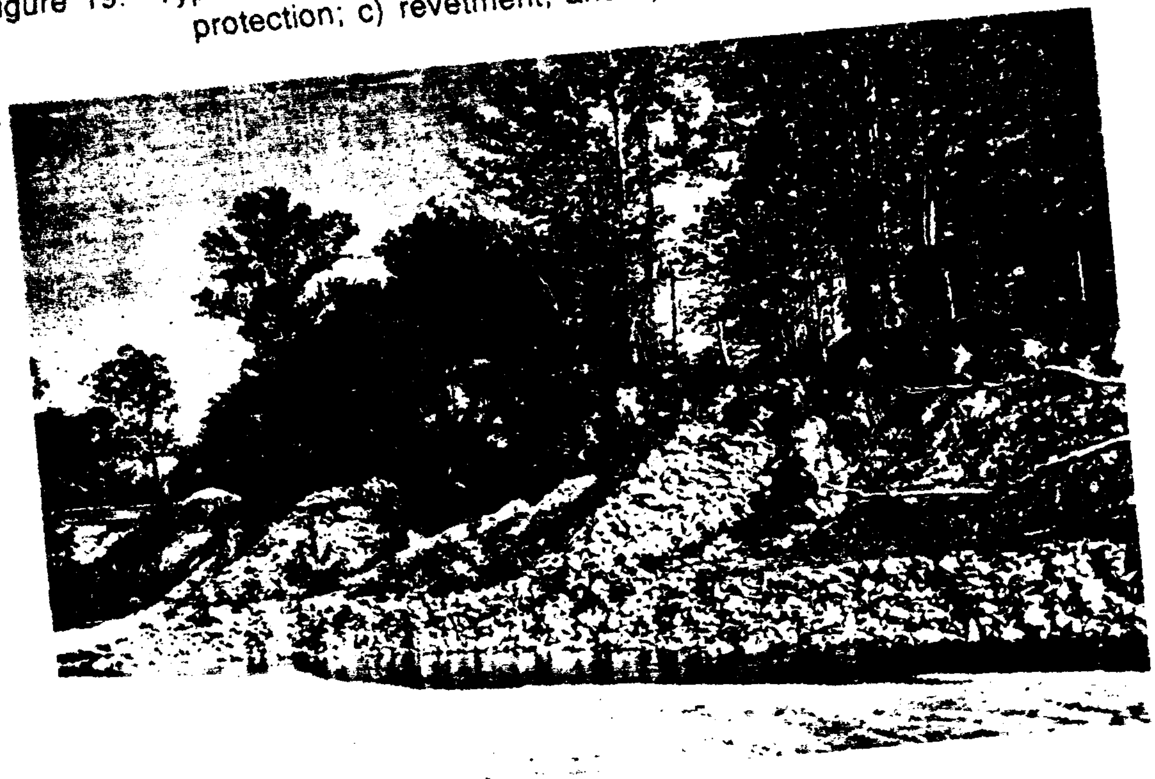
Tension Cracks notes whether there are tension cracks behind the bank (Fig. 21). Tension cracks develop vertically down from the ground surface behind steep banks and greatly reduce the stability of the bank with respect to mass failure. Their presence indicates that the bank is prone to geotechnical instability and potential mass failure due to gravity.

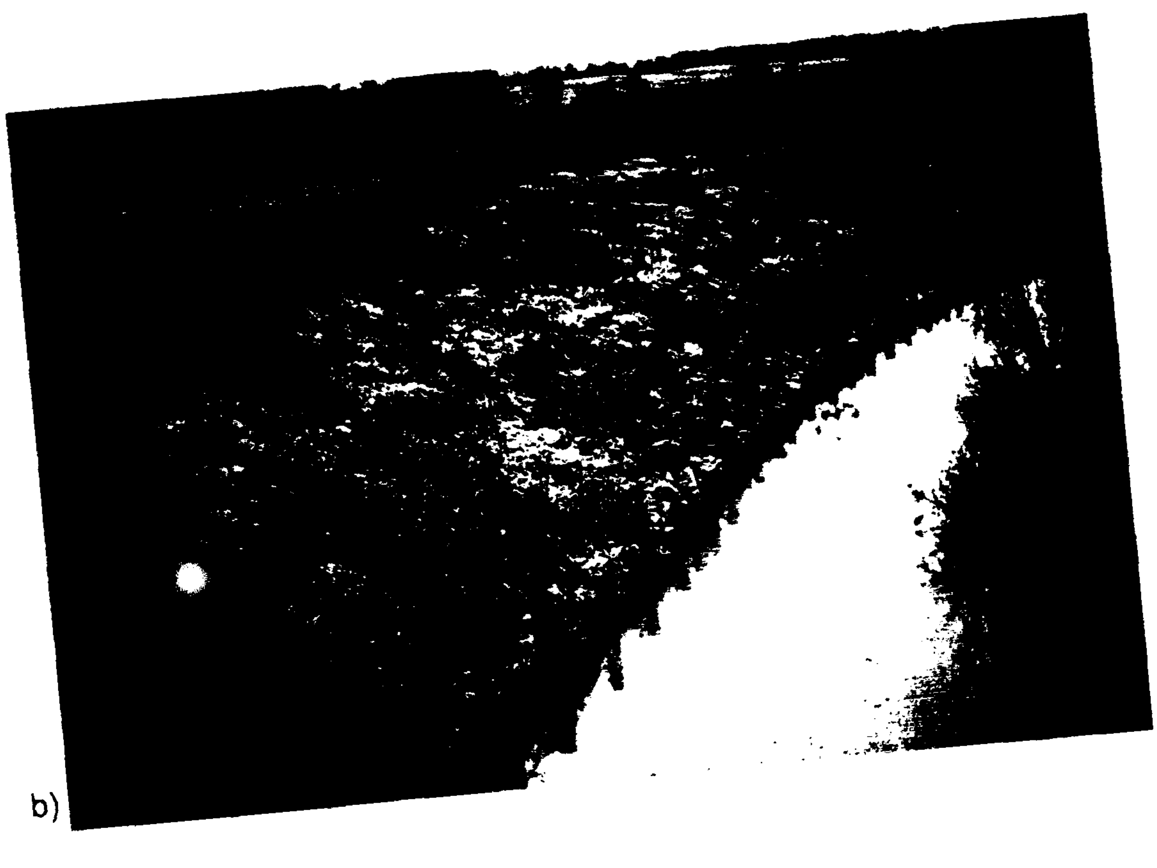
Crack Depth records the depth of tension cracking as a proportion of the total bank height. As a general rule, cracks rarely exceed a depth of half the total bank height.

Distribution of Bank Materials in Bank Profile (Material Types 1 - 4) defines the distribution of up to 4 bank materials through the bank. This can be of crucial importance to bank stability. For example, the occurrence of a weak, noncohesive layer close to top of a layered bank is of little consequence, but the same layer at the toe could allow rapid undercutting and/or piping, leading to a mass failure of the overlying layers.

Figure 19. Types of bank protection: a) Hard points; b) Toe protection; c) revetment; and d) dyke fields

a)





b)

c)

d)

Figure 20. Typical bank profiles

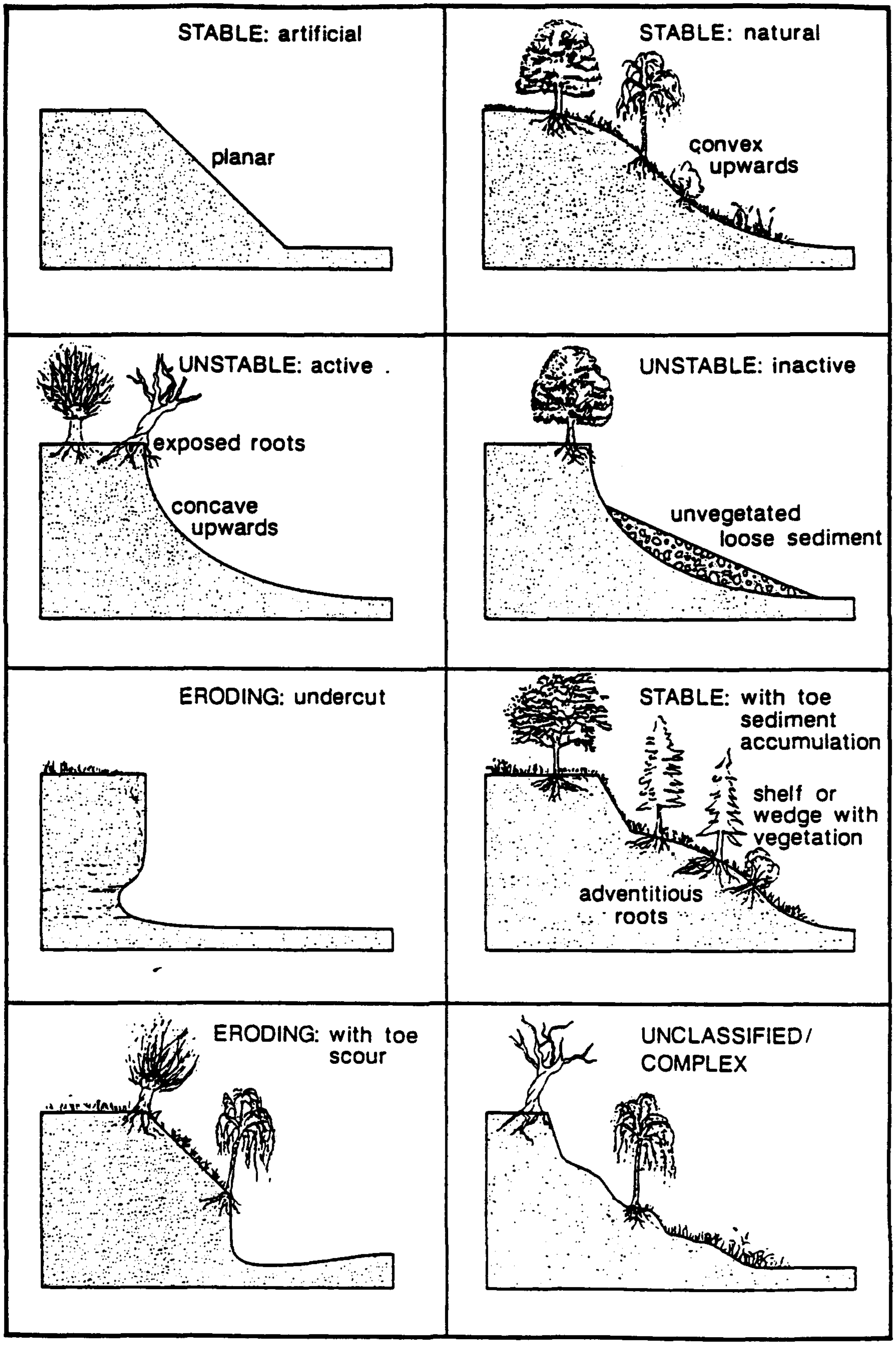
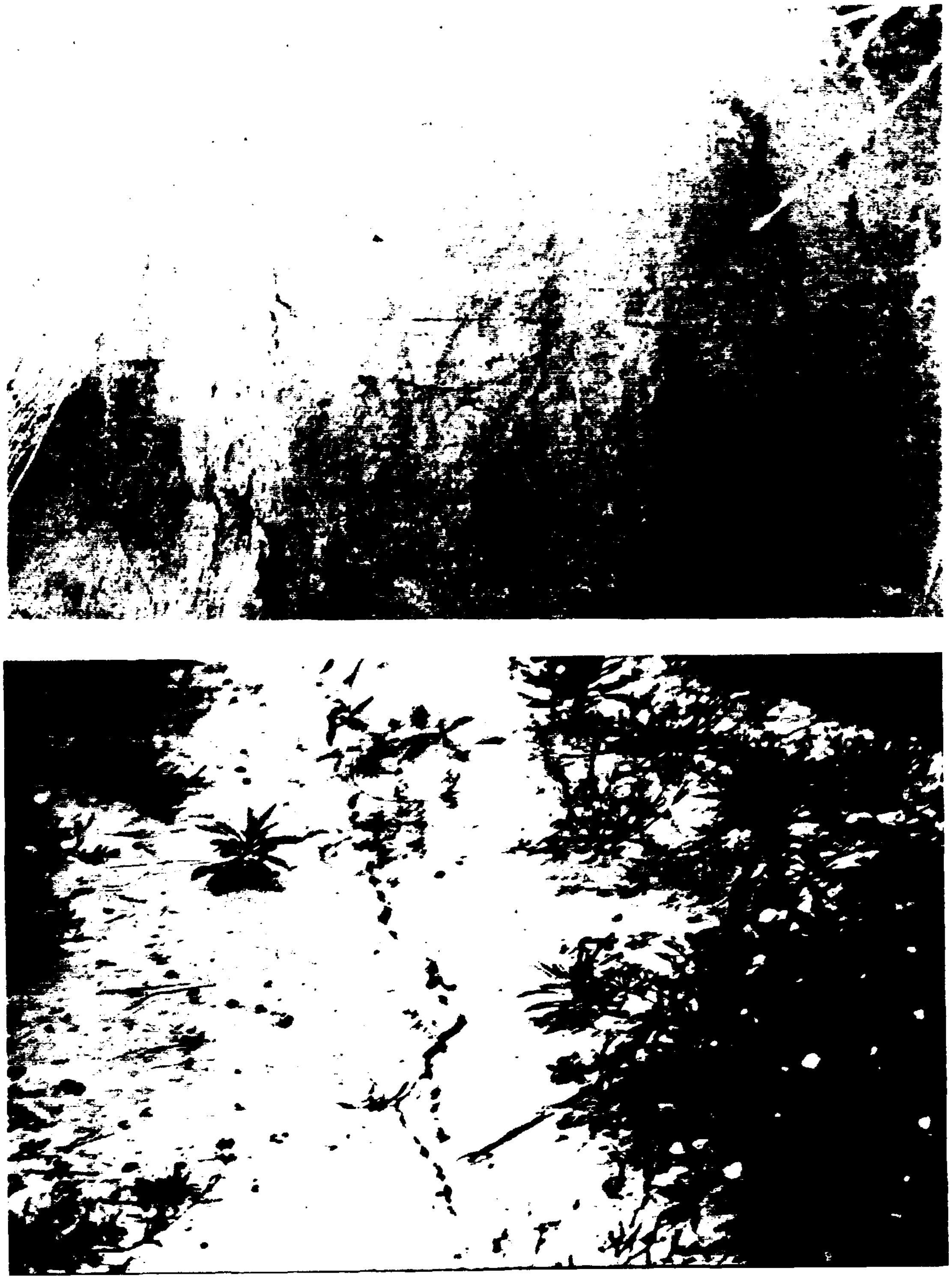


Figure 21. Tension cracking behind a steep, eroding river bank
a) Crack behind active failure block; b) New crack forming at flood plain surface behind bankline

a)



b)

Part 9: Left Bank Vegetation

This part has 12 topics. The important role of bank vegetation in affecting bank processes and stability is now recognized by both engineers and geomorphologists. Vegetation effects may be either beneficial or detrimental to bank stability depending on the nature of the vegetation and the geomorphic environment. Also, vegetation can be a useful indicator of the condition of the bank. Therefore, vegetation is covered in some detail in the reconnaissance.

Vegetation broadly classifies the types of flora found on the bank face itself.

Orientation records the angle at which bank vegetation is leaning over. Vertical vegetation generally indicates stability while leaning vegetation, especially trees, is a sure sign of wind-throw and/or bank instability.

Tree Types recognizes that deciduous and coniferous trees have different effects on bank stability. Compared to deciduous trees, conifers are shallow rooted and lack a vegetative understorey. Usually, deciduous trees are more effective in helping to stabilize a bank through root reinforcement than are conifers.

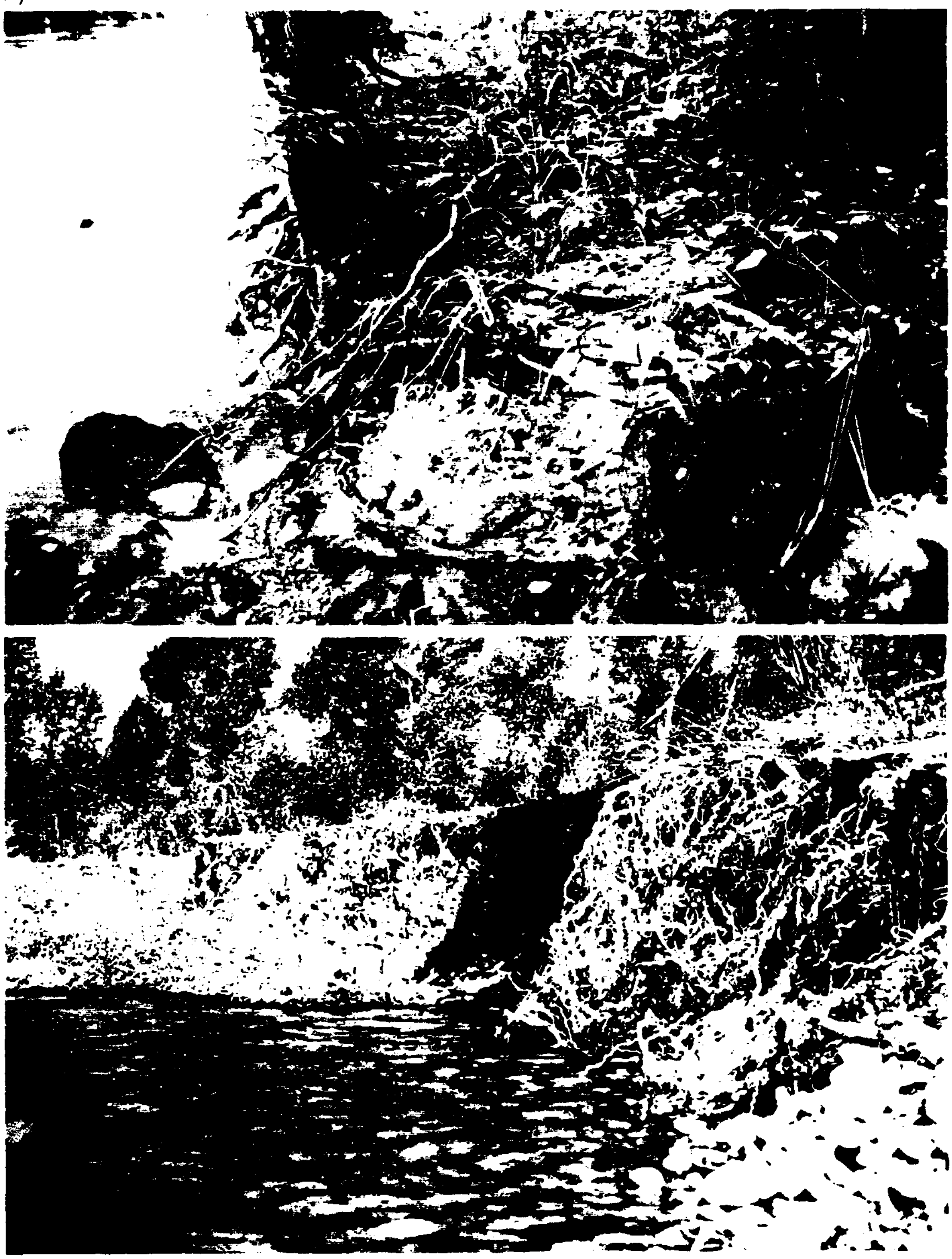
Tree Species allows the user to record in detail the actual trees present if they can be identified. Different species have different degrees of root reinforcement of the soil, vulnerability to wind-throw and flood tolerance which can be useful in interpreting their significance to channel stability.

Density and Spacing describe the degree of vegetative cover over the bank face. Density refers to the closeness of packing together of plant stems. The higher the density, the better the erosion protection, but also the greater the flow resistance of the vegetation. Spacing describes how the vegetation is spread over the bank. Particularly, it refers to whether there are clumps of vegetation with gaps in between which the flow can attack, whether there are closely spaced clumps of plants, or whether there is a continuous cover of plants. It differs from density. For example, it is common for dense vegetation to be growing in widely spaced clumps, with bare soil in between which the flow is able to attack and erode.

Roots defines the relationship between the vegetation roots and the bank surface (Fig. 22). If the bank face has not moved substantially, then the roots are normally found just below the soil surface. If sediment is accumulating on the bank, vegetation produces adventitious roots into the new sediment as the ground surface moves up relative to the plant. If the bank is eroding, plant roots are exposed as the ground surface moves back relative to the plant. If erosion is rapid then roots poke

Figure 22. Plant roots growing in banks subject to : a) slow erosion; and b) rapid erosion

a)



b)

straight out of the bank face. But if erosion is slow, the exposed roots will tend turn back and grow back into the bank face. Hence the state of the roots can be used to infer the present trend in bank deposition or erosion.

Location defines the position of the vegetation on the bank profile. Generally, vegetation (especially trees) at the bank top is less effective in helping to stabilize the bank than that lower on the bank. This is the case because: i) the surcharge weight of woody vegetation at the bank top acts to promote failure, while that low on the bank may load the bank against failure; ii) trees low on the bank are less exposed and are less vulnerable to wind-throw; iii) closely spaced trees low on the banks may have a buttressing effect; iv) vegetation low on the bank reduces near bank velocities and attack on the bank toe. While vegetation low on the banks does induce more flow resistance than that higher on the bank, recent research shows that this will only result in a significant lowering of in-channel conveyance in channels of very low width to depth ratio (less than about 10) (Masterman and Thorne, In Press).

Diversity deals with the mixture of vegetative types present. Diversity is positively correlated with age. Generally a mature ecosystem with a wide variety of species and types is more beneficial than a monostand of one plant type. Climax-vegetation is a mature ecosystem in which there is no longer any succession of plant species with time. Ecologically bank erosion plays a beneficial role in the renewal of the channel environment through destroying overly mature climax-vegetation.

Health notes the state of the vegetation. Dead or dying vegetation is a serious liability to bank stability. It is vulnerable to wind-throw, drags down the bank and, if it falls into the channel, dead wood may divert the flow and cause bed scour and bank erosion. However, woody debris can also create flow retarding log-jams that have beneficial hydraulic, sediment storage and habitat effects so long as potential flooding is not an issue. Within the bank the cavities left by rotted-out roots of dead trees weaken the bank and provide ready pathways for seepage and piping processes (see Parts 10 and 11).

Age can be a useful guide to the history of the bank. Mature vegetation can only develop on a stable bank, while a predominance of young, immature vegetation hints at recent instability. Vegetation age can be estimated eye by field workers with experience of the local species, but more accurate ages must be based on coring of trees to count the annual rings. This requires the right tree coring tools and expertise.

Fallen trees which are not dead produce new stems which grow vertically from the downed trunk (Fig. 23). Breaking off such a stem and counting the annual rings is a good way to gauge the time elapsed since the failure.

Height is a factor in determining the possible effect of vegetation in dragging down the bank and in impeding near-bank flow in the channel. Tall trees (particularly on the upper bank or top bank) may drag down a section of bank by toppling into the channel through either their surcharge weight, or due to wind-throw. Tall vegetation has a higher effective roughness height and produces significant flow resistance in low width/depth ratio channels. The height may be noted qualitatively, but space is also provided for a numerical value, if this is required.

Lateral Extent describes the width of the band of bank vegetation along the channel. It refers to how extensive the band is in relation to the riparian corridor (Fig. 24). A wide, extensive band of vegetation along the bank isolates it from the flood plain, protecting it from grazing and trampling by animals and damage by people. A wide band has many advantages to the bank's environment, habitat value and aesthetic appearance as well as its stability. A narrow band or single line of trees is grazed on the bankward side, producing asymmetrical trees and bushes which lean over into the channel and are vulnerable to wind-throw. Encroachment of farming, recreational and commercial activities to the bank top and beyond should be avoided, to create a buffer strip, except where access to the stream is essential. At these locations special provision should be made to protect the bank from damage while allowing free access for stock, people, machinery and maintenance crews.

Bank Profile Sketches are spaces provided for a visual representation of the left bank in the study reach (Fig. 25). The aims are to show the slope profile break points, the geotechnical/sedimentary features and any engineered structures on the bank, and to record any sediment sampling points in different bank layers. Also, photographs showing important bank features should be taken and photo points and orientations marked on the sketch so that they can be relocated and repeated precisely in any future re-surveys. This greatly enhances their value as a guide to bank condition, erosion, bank-line changes and system instability.

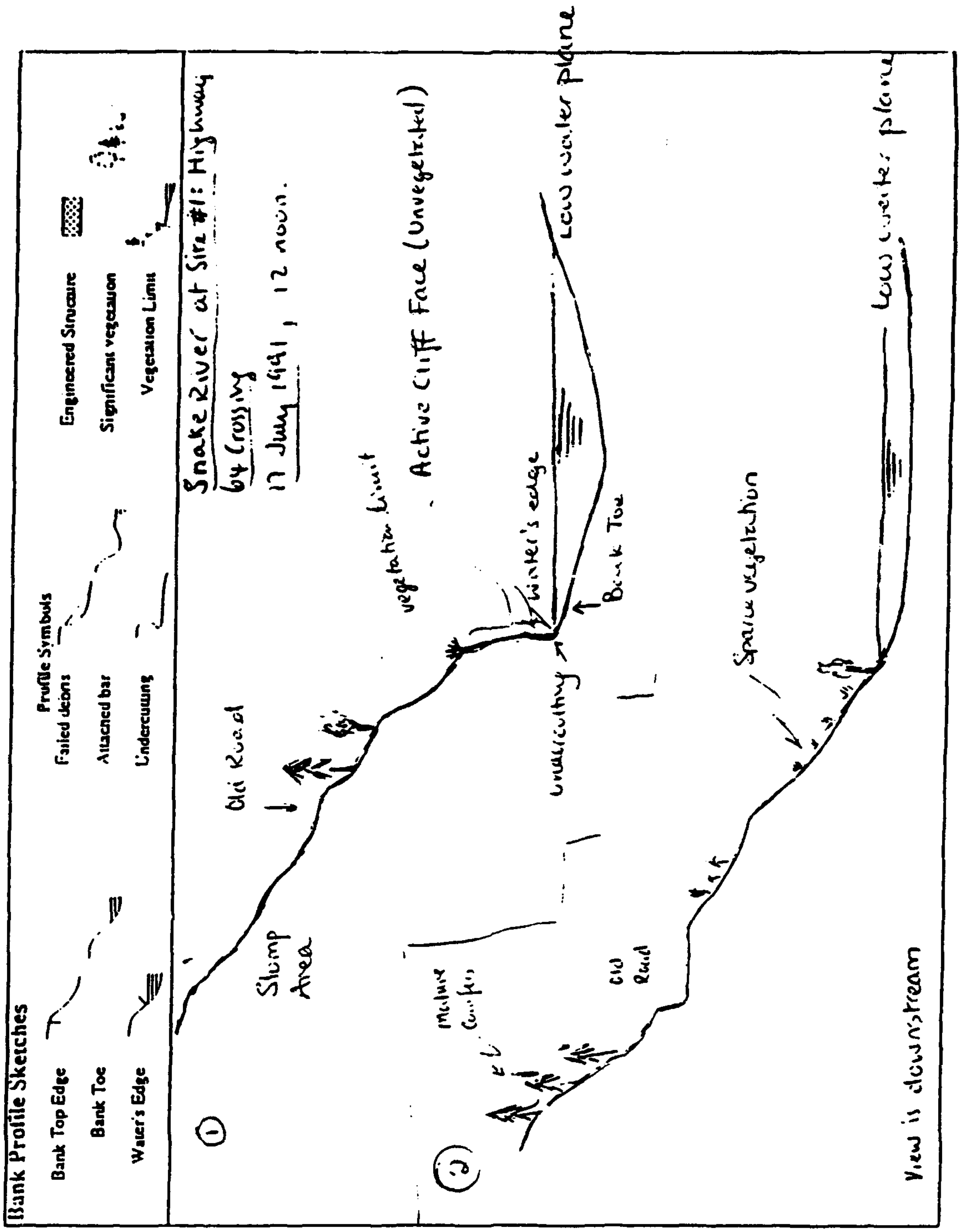
Figure 23. New stems shooting upwards from a downed tree. Counting rings in the stems gauges the time elapsed since failure

Figure 24. Bank vegetation in bands of different widths.
a) Narrow band vulnerable to destabilisation by erosion and wind-throw; b) Deep band resistant to destabilisation

a)

b)

Figure 25. Example bank profile sketch



Part 10: Left Bank Erosion

This part has 10 topics. The aim is to develop a good understanding of the process responsible for erosion and their distribution over the bank, both along the channel and up and down the bank profile. A large proportion of this part is interpretative and the field worker must have some background knowledge of bank erosion to complete this part of the survey.

Erosion Location establishes the position of the eroding area of bank in relation to major channel features. These may, or may not, be the cause of the problem, but it is important to record the relative position of bank erosion in relation to channel planform, bed features and engineering structures.

Present Status establishes the condition of the bank at the time of observation. It may be intact, that is not affected by erosion. If the survey is made at low flow, it may well be that the bank is affected by erosion, but not actually at the time of observation. Such a bank is eroding but dormant. If, however, erosion is actually occuring then the bank is eroding and active. Similarly, a bank advancing through deposition may be either dormant or active at the time of observation.

Rate of Retreat and *Rate of Advance* allow the individual to record the speed of bank-line migration, if it is known. *This may be determined in the office from historical maps and aerial photographs,* in the field from repeated surveys along set ranges, or from local land-owners and other interested parties. However, although potentially valuable, hearsay and other anecdotal evidence must be treated with extreme caution and not accepted as accurate without independent corroboration.

The remaining 7 topics are interpretative and subject to a confidence level.

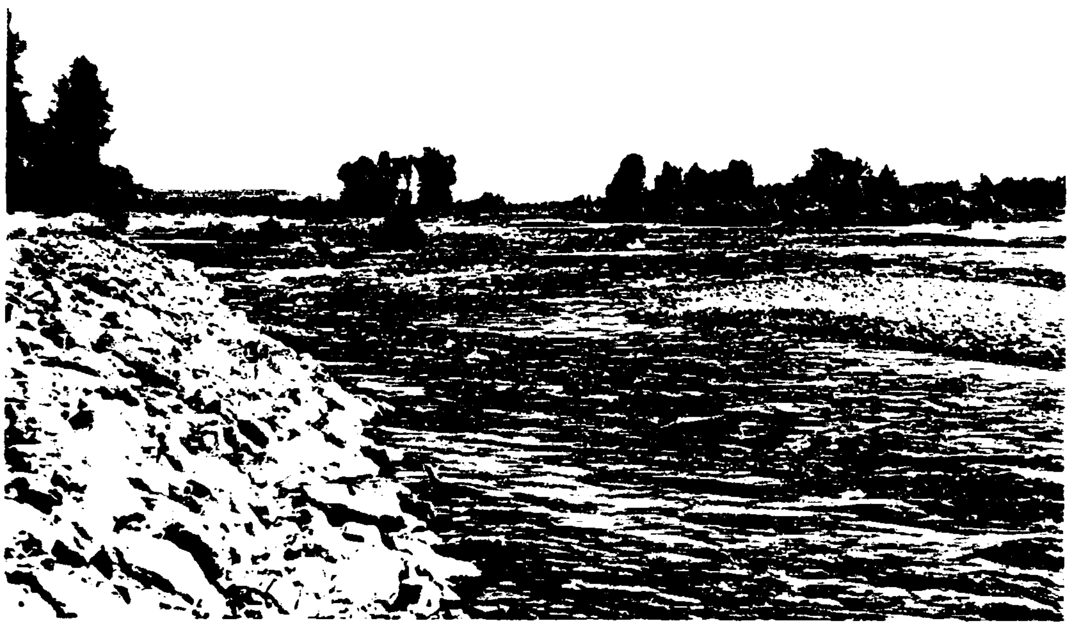
Severity of Erosion puts any erosion into perspective. Nearly all rivers have some bank erosion and this may be quite acceptable: by no means all cases merit analysis or treatment.

Extent of Erosion defines the scale of bank erosion in the river. Usually, this is an essential step in identifying the underlying cause of a bank erosion problem. For example, if a problem is common to the whole fluvial system then a local cause may be unlikely. In terms of bank stabilization, it usually necessary to match the scale of the solution to the scale of the problem. A local solution will not cure a reach or system wide problem and may well be ineffective in the medium to long-term.

Processes attempts to identify the processes responsible for bank erosion (Fig. 26). This is not an easy task and often

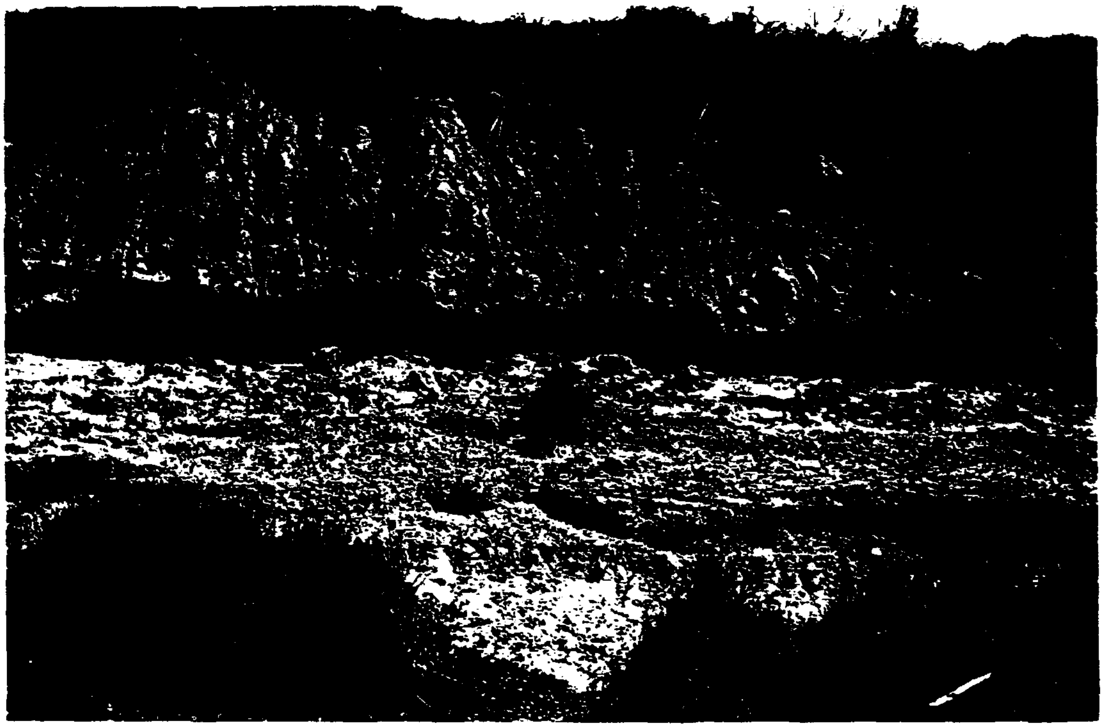
Figure 26. Bank erosion processes observed in the field.
a) Parallel flow; b) impinging flow; c) piping;
d) freeze/thaw; e) sheet erosion+rilling/gullying;
f) wind waves; g) vessel forces and resulting erosion

a)



b)

c)

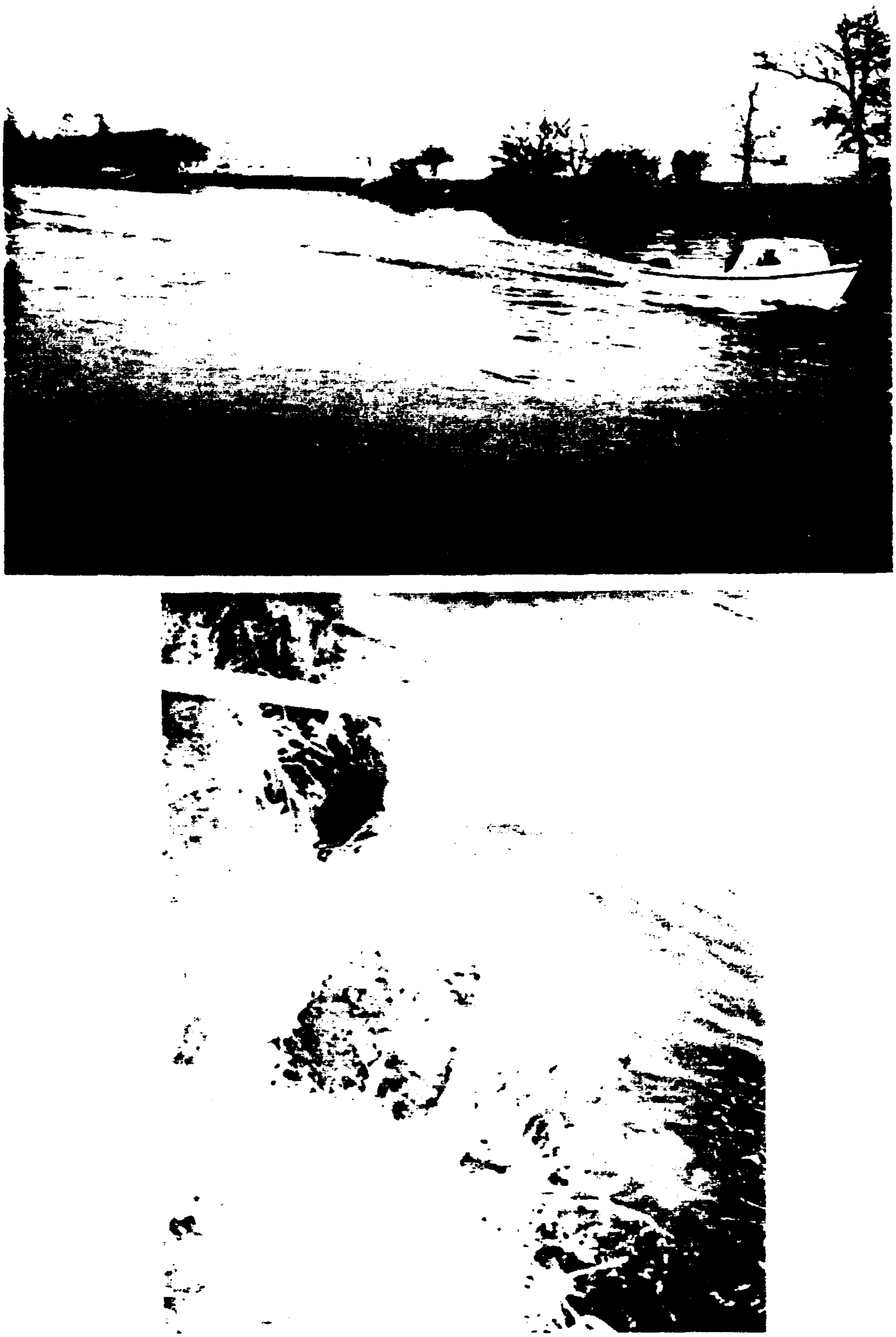


d)

e)

f)

g)



requires some training. It is assumed here that the individuals undertaking the survey are somewhat familiar with erosion processes and field recognition of the effects of different processes on the bank surface. Some guidance is given here to augment the individual's knowledge

Parallel Flow erosion is the detachment and removal of intact grains or aggregates of grains from the bank face by flow along the bank. Evidence includes: observation of high flow velocities close to the bank; near-bank scouring of the bed; under-cutting of the toe/lower bank relative to the bank top; a fresh, ragged appearance to the bank face; absence of surficial bank vegetation.

Impinging Flow erosion is detachment and removal of grains or aggregates of grains by flow attacking the bank at a steep angle to the long-stream direction. Impinging flow occurs in braided channels where braid-bars direct the flow strongly against the bank, in tight meander bends where the radius of curvature of the outer bank is less than that of the channel centerline, and at other locations where an in-stream obstruction deflects and disrupts the orderly flow of water. Evidence includes: observation of high flow velocities approaching the bank at an acute angle to the bank; braid or other bars directing the flow towards the bank; tight meander bends; strong eddying adjacent to the bank; near-bank scouring of the bed; under-cutting of the toe/lower bank relative to the bank top; a fresh, ragged appearance to the bank face; absence of surficial bank vegetation.

Piping is the caused by groundwater seeping out of the bank face. Grains are detached and entrained by the seepage flow (also termed sapping) and may be transported away from the bank face by surface run-off generated by the seepage, if there is sufficient volume of flow. Piping is especially likely in high banks or banks backed by the valley side, a terrace, or some other high ground. In these locations the high head of water can cause large seepage pressures to occur. Evidence includes: pronounced seep lines, especially along sand layers or lenses in the bank; pipe shaped cavities in the bank; notches in the bank associated with seepage zones and layers; run-out deposits of eroded material on the lower bank. Note that the effects of piping erosion can easily be mistaken for those of wave and vessel force erosion. (see papers by Hagerty and Hagerty, 1989 and by May, 1982).

Freeze/thaw is caused by sub-zero temperatures which promote freezing of the bank material. Ice wedging cleaves apart blocks of soil. Needle-ice formation loosens and detaches grains and crumbs at the bank face. Freeze/thaw activity

seriously weakens the bank and increases its erodibility. Evidence includes: periods of below freezing temperatures in the river valley; a loose, crumbling surface layer of soil on the bank; loosened crumbs accumulated at the foot of the bank after a frost event; jumbled blocks of loosened bank material.

Sheet erosion is the removal of a surface layer of soil by non-channelised surface run-off. It results from surface water draining over the bank edge, especially where the riparian and bank vegetation has been destroyed by encroachment of human activities. Evidence includes: surface water drainage down the bank; lack of vegetation cover, fresh appearance to the soil surface; eroded debris accumulated on the lower bank/toe area.

Rilling + gullying occurs when there is sufficient uncontrolled surface run-off over the bank to initialise channelised erosion. This especially likely where flood plain drainage has been concentrated (often unintentionally) by human activity. Typical locations might be near buildings and parking lots, stock access points and along stream-side paths. Evidence includes: a corrugated appearance to the bank surface due to closely spaced rills; larger gullied channels incised into the bank face, headward erosion of small tributary gullies into the flood plain surface, eroded material accumulated on the lower bank/toe in the form of alluvial cones and fans.

Wind waves cause velocity and shear stresses to increase and generate rapid water level fluctuations at the bank. They cause measurable erosion only on large rivers with long fetches which allow the build up of significant waves. Evidence includes: large channel width or long, straight channel and an acute angle between eroding bank and longstream direction; a wave-cut notch just above normal low water plane; a wave-cut platform or run-up beach around normal low-water plane. Note that it is easy to mistake the notch and platform produced by piping and sapping for one cut by wave action (see papers by Hagerty and Hagerty, 1989 and May, 1982).

Vessel Forces can generate bank erosion in a number of ways. The most obvious way is through the generation of surface waves at the bow and stern which run up against the bank in a similar fashion to wind waves. In the case of large vessels and/or high speeds these waves may be very damaging. If the size of the vessel is large compared to the dimensions of the channel hydrodynamic effects produce surges and drawdown in the flow. These rapid changes in water level too can loosen and erode material on the banks through generating rapid pore water pressure fluctuations. If the vessels are relatively close to the bank propeller wash can erode material and re-suspend sediments on the bank below the water surface. Finally,

mooring vessels along the bank may involve mechanical damage by the hull. Evidence includes: use of river for navigation; large vessels moving close to the bank; high speeds and observation of significant vessel-induced waves and surges; a wave-cut notch just above the normal low-water plane; a wave-cut platform or "spending" beach around normal low-water plane. Note that it is easy to mistake the notch and platform produced by piping and sapping for one cut by vessel forces (see papers by Hagerty and Hagerty, 1989 and May, 1982).

Ice rafting erodes the banks through mechanical damage to the banks due to the impact of ice-masses floating in the river and due to surcharging by ice cantilevers during spring thaw. Evidence includes: severe winters with river prone to icing over; gouges and disruption to the bank line; toppling and cantilever failures of bank+attached ice masses during spring break-up.

Other erosion processes (trampling by stock, damage by fishermen etc.) could be significant but it is impossible to list them all. If some other erosive process is identified tick this box and write it in below.

Distribution of Each Process on the Bank recognizes that more than one erosion process may operate on a bank. Different processes may be responsible for eroding different parts of the bank. The distribution of up to four different processes over the bank may be delineated here. This is significant because the distribution of different erosion processes has geomorphic implications and may require special consideration when stabilizing the bank.

Part 11: Left Bank Geotech Failures

This part has 10 topics. Serious bank retreat often involves geotechnical bank failures as well as direct erosion by the flow. Such failures are often referred to as "bank sloughing" or "caving", but these terms are poorly defined and their use is to be discouraged. The potential for bank failure can have implications for plans to stabilize a bank. The aim of this part is to identify any geotechnical instability, classify the modes of failure and note their distribution over the bank.

Failure Location establishes the position of the failing area of bank in relation to major channel features. These may, or may not, be the cause of the problem but it is important to record the relative position of bank failure in relation to channel planform, bed features and engineering structures. Failures will usually coincide with the location of bank erosion, but this may not always be the case. Where instability and

retreat are the result of weakness or processes operating within the bank, it may not be in an area of active erosion (see for example papers by Hagerty and Hagerty, 1989).

Present Status establishes the condition of the bank at the time of observation. It may be stable, that is not affected by geotechnical instability and showing no evidence of past failures. If the bank appears to be stable, but does show evidence of recent, past failures, it may be classified as unreliable. This indicates that failures have occurred on the bank and, therefore, that they might recur in the future. Most instability is associated with saturated conditions in the bank and failures tend to occur during, or soon after, high flow stages in the channel. If the survey is made at low flow and there has not been heavy rain or snowmelt for some time, it may be that although the bank is potentially unstable, it is stable at the time of observation. Such a bank is unstable but dormant because should saturated and/or rapid drawdown conditions occur, it would be likely to fail. If failures are actually observed then the bank is unstable and active.

Failure Scars + Blocks notes the presence and appearance of two prominent features produced by bank instability. Scars are the failure surfaces left in the bank when a block of material falls, slumps or slides away. Blocks are the more or less intact pieces of the failure mass which come to rest at the bank toe, or on the lower bank. Immediately after failure scars and blocks are fresh, with sharp edges, but weathering softens their appearance as time passes.

The remaining 7 topics are interpretative and subject to a confidence level.

Instability: Severity puts any instability into perspective. Nearly all rivers have some bank instability and this may be quite acceptable: not all cases merit analysis or treatment.

Instability: Extent defines the scale of bank collapse in the river. Usually, this is an essential step in identifying the underlying cause of a bank instability problem. For example, if a problem is common to the whole fluvial system then a local cause may be unlikely. In terms of bank stabilization, it usually necessary to match the scale of the solution to the scale of the problem. A local solution will not cure reach or system wide problems and may be ineffective in the medium to long-term.

Failure Mode attempts to identify the type of failures resulting from bank instability (Fig. 27). This is not an easy task and often requires some training. It is assumed here that the individuals undertaking the survey are somewhat familiar with slope failure mechanics and bank collapse.

Figure 27. Examples of different modes of geotechnical stream bank failure. a) Soil fall; b) rotational slip; c) slab failure; d) cantilever failure; e) pop-out failure; f) piping; g) dry granular flow; h) wet earth flow; i) example 'other' failure mode - cattle trampling

a)

b)

c)

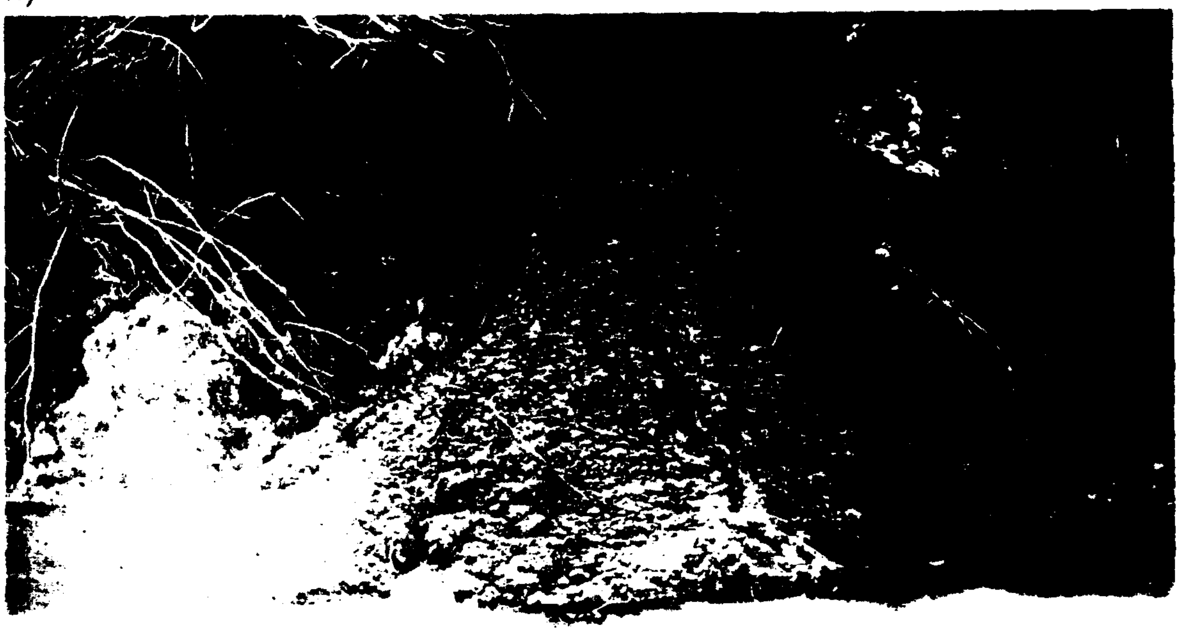
d)

e)

f)

g)

h)



i)

Interpretation rests on recognition of the geometry of the bank which results from different mechanisms. Some guidance is given here.

Soil/rock fall occurs only on a steep bank, where grains, grain assemblages or blocks fall into the channel. Such failures are found on steep, eroding banks of low operational cohesion. Soil and rock falls often occur when a stream undercuts the toe of a sand, gravel or deeply weathered rock bank. Evidence includes: very steep bank; debris falling into the channel; failure masses broken into small blocks; no rotation or sliding failures.

Shallow slide is a shallow seated failure along a plane somewhat parallel to the ground surface. Such failures are common on banks of low cohesion. Shallow slides often occur as secondary failures following rotational slips and/or slab failures. Evidence includes: weakly cohesive bank materials; thin slide layers relative to their area; planar failure surface; no rotation or toppling of failure mass.

Rotational slip is the most widely recognised type of mass failure mode. A deep seated failure along a curved surface results in back-tilting of the failed mass toward the bank. Such failures are common in high, strongly cohesive banks with slope angles below about 60°. Evidence includes: banks formed in cohesive soils; high, but not especially steep, banks; deep seated, curved failure scars; back-tilting of top of failure blocks towards intact bank; arcuate shape to intact bank line behind failure mass.

Slab-type block failure is sliding and forward toppling of a deep seated mass into the channel. Often there are deep tension cracks in the bank behind the failure block. Slab failures occur in cohesive banks with steep bank angles, greater than about 60°. Such banks are often the result of toe scour and under-cutting of the bank by parallel and impinging flow erosion. Evidence includes: cohesive bank materials; steep bank angles; deep seated failure surface with a planar lower slope and nearly-vertical upper slope; deep tension cracks behind the bank-line; forward tilting of failure mass into channel; planar shape to intact bank-line behind failure mass.

Cantilever failure is the collapse of an overhanging block into the channel. Such failures occur in composite and layered banks where a strongly cohesive layer is underlain by a less resistant one. Under-mining by flow erosion, piping, wave action and/or pop-out failure leaves an overhang which collapses by a beam, shear or tensile failure. Often the upper layer is held together by plant roots. Evidence includes: composite or layered bank stratigraphy; cohesive layer

underlain by less resistant layer; under-mining; overhanging bank blocks; failed blocks on the lower bank and at the bank toe.

Pop-out failure results from saturation and strong seepage in the lower half of a steep, cohesive bank. A slab of material in the lower half of the steep bank face falls out, leaving an alcove-shaped cavity. The over-hanging roof of the alcove subsequently collapses as a cantilever failure. Evidence includes: cohesive bank materials; steep bank face with seepage area low in the bank; alcove shaped cavities in bank face.

Piping failure is the collapse of part of the bank due to high groundwater seepage pressures and rates of flow. Such failures are an extension of the piping erosion process described in Part 9, to the point that there is complete loss of strength in the seepage layer. Sections of bank disintegrate and are entrained by the seepage flow (termed sapping). They may be transported away from the bank face by surface run-off generated by the seepage, if there is sufficient volume of flow. Evidence includes: pronounced seep lines, especially along sand layers or lenses in the bank; pipe shaped cavities in the bank, notches in the bank associated with seepage zones, run-out deposits of eroded material on the lower bank or beach. Note that the effects of piping failure can easily be mistaken for those of wave and vessel force erosion.

Dry granular flow describes the flow-type failure of a dry, granular bank material. Other terms for the same mode are ravelling and soil avalanche. Such failures occur when a noncohesive bank at close to the angle of repose is undercut, increasing the local bank angle above the friction angle. A carpet of grains rolls, slides and bounces down the bank in a layer up to a few grains thick. Evidence includes: noncohesive bank materials; bank angle close to the angle of repose; undercutting, toe accumulation of loose grains in cones & fans.

Wet earth flow failure is the loss of strength of a section of bank due to saturation. Such failures occur when water-logging of the bank increases its weight and decreases its strength to the point that the soil flows as a highly viscous liquid. This may occur following heavy and prolonged precipitation, snow-melt or rapid drawdown in the channel. Evidence includes: sections of bank which have failed at very low angles; areas of formerly flowing soil that have been preserved when the soil dried out; basal accumulations of soil showing delta-like patterns and structures.

Other failure modes could be significant but it is impossible to list them all. If some other type of failure is identified tick this box and write it in below.

Distribution of Each Mode on the Bank recognizes that different failure modes may be involved in the collapse of different parts of the bank. The distribution of up to four different modes may be delineated here. This is significant because the distribution of different failure modes has geomorphic implications and may require special consideration when stabilizing the bank.

Part 12: Left Bank Toe Sediment Accumulation

The part has 9 topics. The aims are to characterize the balance between sediment supply and removal at the bank toe and to establish the degree of toe scour or sediment accumulation there. The sediment balance defines the state of basal endpoint control of the bank.

Banks which have net toe erosion (under-cutting) are certain to become less stable and to retreat more rapidly in the future unless a more resistant bank material is encountered or steps are taken to stabilize the bank (Fig. 28a). When stabilizing such banks, special steps must be taken in the design to either eliminate or allow for serious toe scour.

Banks which have neither net toe erosion or deposition will continue to retreat at about a constant rate because, on average, failed material is removed by basal clean-out about as quickly as it is generated by bank erosion and failure (Fig. 28b). Only the usual degree of toe scour protection is needed on such banks.

Banks with net toe deposition should show increased stability and a reduced rate of retreat, all else being equal (Fig. 28c). This is achieved through bank shelf building - the accumulation of a low angle sediment wedge at the bank toe. Hence the degree of bank shelf development is a good indicator of the tendency of the bank towards stability. Given the opportunity, vegetation invades the stable toe area and shelf quite quickly. Therefore, toe vegetation can be used as a guide to the age and permanence of a bank shelf. Banks with developing, permanent shelves should not normally require structural bank protection.

Stored Bank Debris notes the presence and type of material found in storage at the bank toe. Note that a bank shelf is made up mostly of debris derived from bank erosion and failure which has not been removed by the flow. Bed and bar sediment should not be the primary material, as this indicates that the feature is an attached bar rather than a bank shelf. Bars are hydraulic roughness elements and bed sediment stores which play different roles in channel process to the bank sediment storage and buttressing roles of a bank shelf.

Figure 28. Typical bank toe profiles: a) Concave upwards (active erosion); b) Planar (temporary storage) and; c) convex upwards (net accumulation)

a)

b)

c)

Vegetation at the broad scale classifies the types of flora found on the bank shelf at the toe.

Age can be a useful guide to the recent history of undercutting or sediment accumulation (Fig 29). Old and mature vegetation clearly can only develop on a stable bank shelf. A lack of vegetation or a predominance of young, immature plants hints at a recently deposited shelf that may be a temporary feature, being destroyed at high flow.

Tree Species allows the user to record in detail the actual trees present if they can be identified. Different species have different degrees of root reinforcement of the soil, vulnerability to wind-throw and flood tolerance which can be useful in interpreting their significance to channel stability.

Health identifies the state of the shelf vegetation. Dead or dying vegetation can quickly become a serious liability to the shelf, bank and channel stability unless it is dense enough to form a natural crib wall, protecting the toe and lower bank.

Roots defines the relationship between the vegetation roots and the bank shelf surface. If the elevation of the shelf surface has not changed substantially, then the roots are normally found just below the surface. If the shelf is accumulating, vegetation produces adventitious roots into the new sediment as this moves the ground surface up relative to the plant. If the shelf is eroding, plant roots are exposed as the ground surface moves down relative to the plant. Hence, the roots can be used to infer the present trend in shelf growth or erosion.

The remaining 3 topics are interpretative and subject to a confidence level.

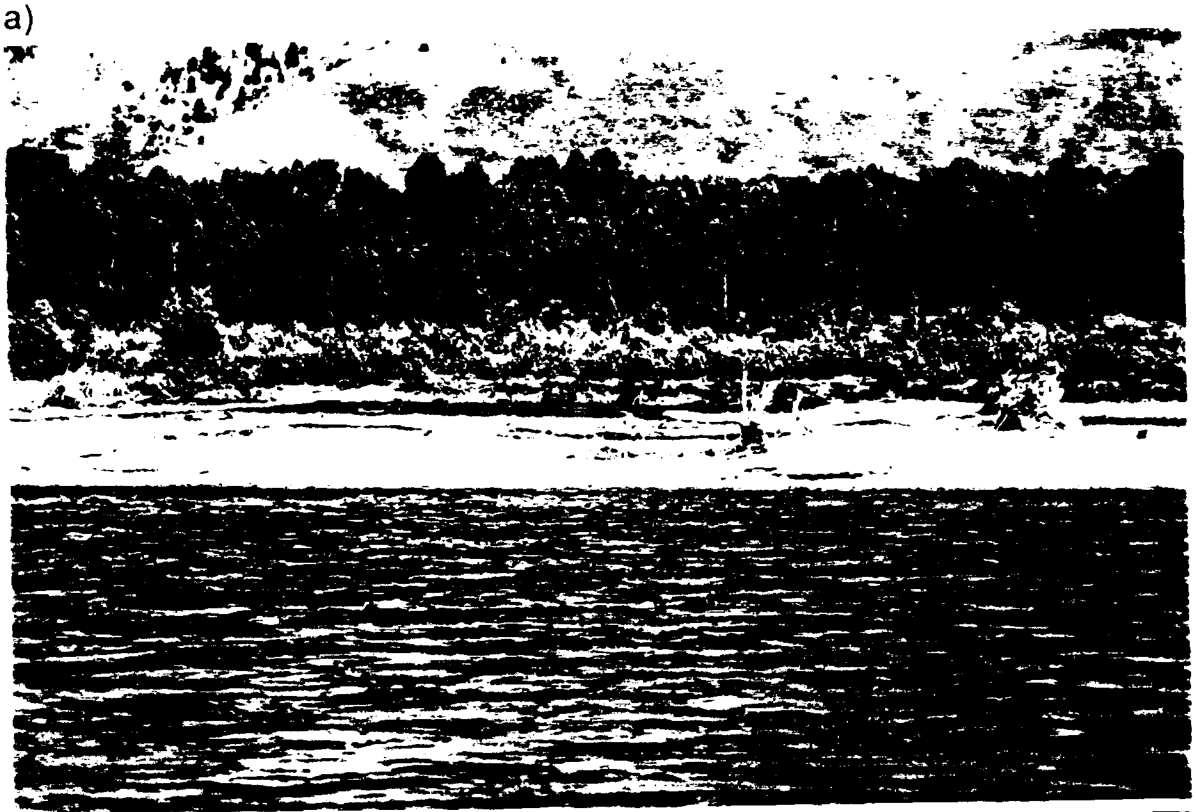
Toe Bank Profile classifies the shape of the bank toe area. A planar slope is either artificial or is formed in totally disaggragated, effectively non-cohesive debris from bank erosion and failure. This material is most likely being stored at the toe as a basal wedge, prior to removal by a high flow event in the channel. A concave upward profile is usually associated with toe erosion and little sediment storage at the toe. A convex upward profile indicates a considerable and accumulating storage of material as a bank shelf.

Present Debris Storage estimates the amount of bank debris currently stored at the bank toe.

Sediment Balance identifies on the basis of the evidence observed whether the amount of bank debris in the toe area is increasing (accumulating), staying about constant (steady state) or decreasing (under-cutting). If it is not possible to judge this then the "unknown" box may be ticked.

Figure 29. Bank Shelf vegetation of different ages. a) Immature vegetation on a shelf in front of mature flood plain forest; b) mature vegetation on bench on left bank; c) old trees on shelves on both banks

a)



b)

c)

2.6 SECTION 5 - RIGHT BANK SURVEY

Section 5 repeats the bank survey for the other river bank. The section consists of parts 13 to 17 which are indentical to parts 7 to 12 in Section 4.

3. CONCLUSIONS

The Stream Reconnaissance sheets presented here are an attempt to develop a system to observe and record information pertaining to channel form, fluvial processes, sediment impacts and stability problems on natural water courses. They have been tested and modified in the light of comments made by professional engineers working in District Offices in five American States. However, their development and improvement is on-going and will benefit from further experience. Any individual who uses the sheets should bear their nature in mind. Any experience in using the sheets would be of interest to the developers, who would be grateful for feedback and comments. Please address any correspondence to either of the Principal Investigator named on the front cover of this document or the relevant staff at the Hydraulics Laboratory, WES.

4 ACKNOWLEDGEMENTS

The original idea for the sheets comes from a paper by Kellerhals, Church and Bray (1976) and their inspiration is fully acknowledged. The work undertaken in this project benefitted enormously from the involvement of Brad Comes and Mike Trawle at WES. Brad was originally in charge of the work unit under which the project was performed and he was instrumental in making the early phases of the work a success. Mike Trawle took over the work unit after Mr Comes left the Laboratory, and played an important role in the later phases and particularly the field testing and evaluation of the technique. The support of Mr Tony Thomas at WES is also gratefully acknowledged.

Field testing could not have been undertaken without the positive involvement of Meg Burns (Baltimore District), Dave Berretta (Memphis District), Steve Collingsworth (Ft Worth District), Ed Sing (Sacramento District) and Lester Cunningham (Walla Walla District). Each gave of their time and energy in making the sheets better.

The idea of adding a "confidence level" to the interpretative sections came to me after seeing an "expert system" for channel evolution produced by the staff of Water Engineering and Technology, Ft Collins, Colorado for the Vicksburg Division, US Army Corps of Engineers.

In the field, my research associate Richard Masterman was tireless in his role as route finder, secretary, note keeper, camera operator and helpful adviser.

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13. ABSTRACT *(Maximum 200 words)*

The first objective of this study was to evaluate the potential for practical application of existing bank erosion assessment sheets as an aid to field identification of (a) the state of vertical and lateral channel stability; (b) the relation of local bank retreat to channel instability; (c) the engineering and morphological characteristics of the banks; (d) the dominant erosive forces and processes; (e) the state of bank stability and major failure mechanisms; (f) the severity and extent of bank erosion in the reach; and (g) the input parameters necessary for modeling bank retreat.

The second objective was to undertake field testing of the bank erosion assessment sheets and guidelines in a wide variety of river environments to identify areas of weakness or mechanisms and bank erosion scenarios not covered by them.

The third objective was to further develop the sheets and guidelines to produce an assessment system suitable for routine use nationwide by nonexpert personnel.

(Continued)

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The bank erosion assessment sheets developed as a result of this study, referred to as stream reconnaissance record sheets, and the guidelines developed for their use present a system for the orderly and disciplined collection and recording of comprehensive qualitative and semiquantitative data on streams and rivers. The development of the stream reconnaissance record sheets from this study was based on real-world applications by practicing engineers concerned with actual problems. As such they should be of immediate value to the U.S. Army Corps of Engineers in fulfilling its mission.